Jordan, William Leighton
The ocean: a treatise on ocean currents and tides and their causes, demonstrating the system of the world, 2nd ed., abridged and rev., London: Longmans, Green, 1885, 281 p.

OCEAN CURRENTS

AND THE

SYSTEM OF THE WORLD

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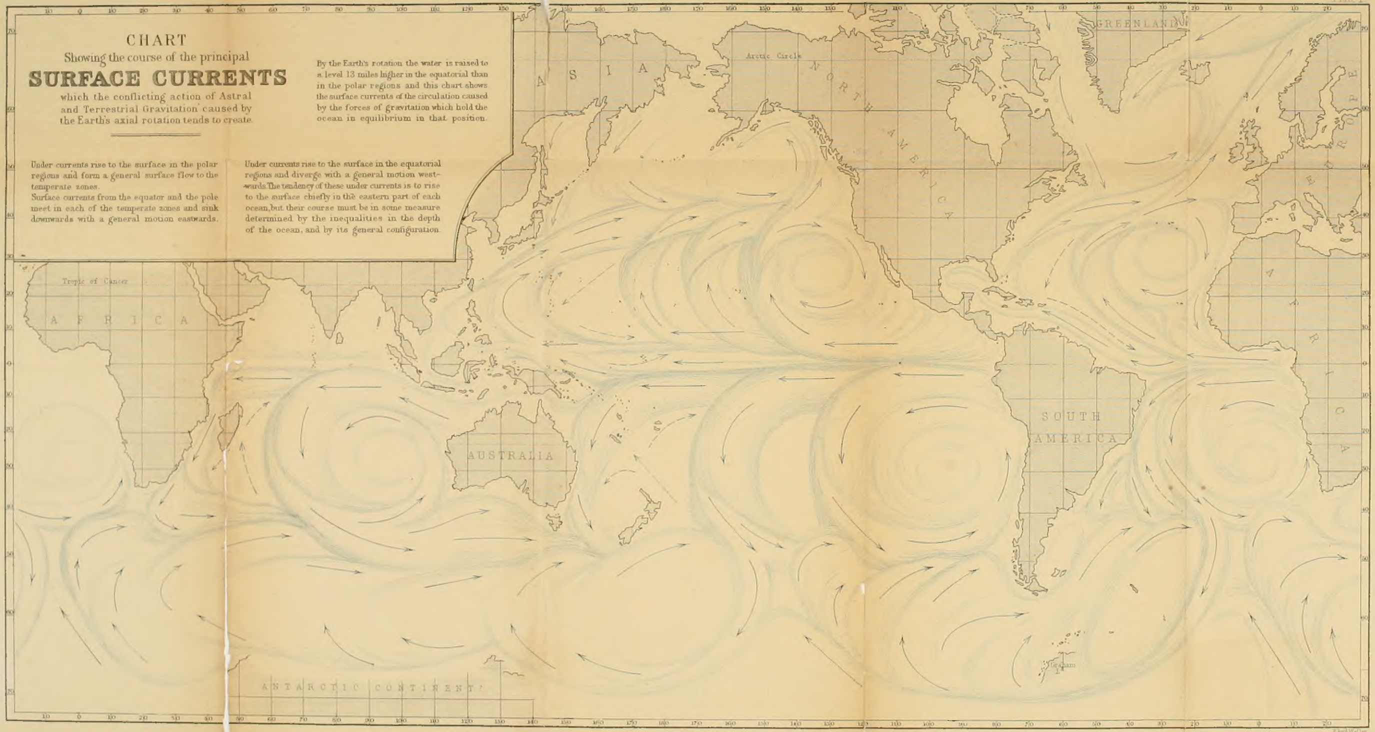
LONDON

Plate I.



London, Longmans & Co.

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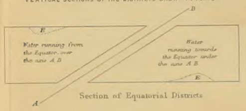
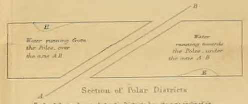
Plate VIII.

VERTICAL SECTIONS OF THE DISTRICTS SHOWN IN PLATE II



Section of Equatorial Districts



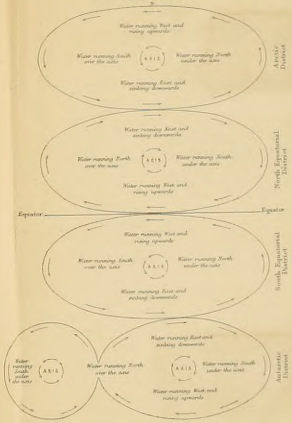
Section of Polar Districts

Each of the two lesser Antarctic Districts has its axis inclined in the opposite direction to that in the Section, but in each the water moving from the Pole passes over the axis, and that moving towards the Pole passes under the axis, just as in the other Polar Districts.

E. Shows the position of Counter Currents.

Plate VIII (a)

HORIZONTAL SECTION, APPLICABLE TO EITHER THE ATLANTIC OR PACIFIC DIVISION OF CURRENTS SHOWN IN THE CHART TAKEN HALF WAY BETWEEN THE SURFACE AND THE BOTTOM OF THE OCEAN.



N.B. The Antarctic Districts are South West of the corresponding Equatorial District, as shown on Plates I and II.

THE OCEAN

A TREATISE ON

OCEAN CURRENTS AND TIDES, AND THEIR CAUSES

DEMONSTRATING

THE SYSTEM OF THE WORLD

WILLIAM LEIGHTON JORDAN, F.R.G.S.

SECOND EDITION, ABRIDGED AND REVISED

LONDON
LONGMANS, GREEN, AND CO.
1885

PREFACE.

'A TREATISE on the Action of Vis-Inertiæ in the Ocean,' published in 1868, was, in some measure, a second edition of 'The Elements, or an Investigation of the Forces which determine the position and movements of the Ocean and Atmosphere,' published in 1866; and the first edition of this present work, published in 1873, was, to a great extent, a third edition of the same, revised and partly re-written.

This second edition of 'The Ocean' has been abridged by the omission of some chapters which have been republished in 'The New Principles of Natural Philosophy,' and minor omissions of matter not closely connected with the subject, and more fully treated in the work just mentioned. Book X., which in the first edition professed to offer merely 'suggestions' as to the action of Vis-Inertiæ in the

heavens, now forms a *demonstration* of the subject as new propositions have been added which clear up what were previously doubtful points. Some additions have also been made in Chapter I., and foot-notes added throughout the volume.

LONDON: *March 27,* 1885.

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BOOK I.

PRELIMINARY

CHAPTER I.

ON THE NATURAL COURSE OF AN INVESTIGATION OF THE CAUSES OF THE MOVEMENTS OF THE OCEAN.

Besides the waves, which rise wherever the surface of the water is ruffled by the wind, two apparently distinct kinds of movement are observable in the ocean: the one a streaming onwards of parts of the ocean through itself, which is taking place more or less in all parts of it, and forms the ocean currents; the other, a movement by which its level is constantly changing—rising in one part as it falls in another. This latter forms the tides, and is an alternate piling up and subsiding of the water, and not a current except where the coast line offers such obstruction as to cause a rush of water.

The first impulse of practical inquirers regarding the causes of ocean currents seems to have been to attribute them to the winds, as ocular demonstration of their action is evident to anyone who watches the ocean waves which are rolled along by every breeze. This apparent action of the winds, together with the general accordance of many of the broad features of

aerial and oceanic circulation, led the first investigators of the subject to regard them as cause and effect ; but difficulties met with by subsequent inquirers endeavouring more accurately to reconcile the observed effects with this suggested cause, led to the consideration that as the burning rays of the sun are constantly pouring down on the equatorial waters, leaving those of the polar regions icy cold, the differences of temperature resulting from this must also to some extent tend to cause currents, as the water endeavours to maintain its equilibrium.

Those investigators who came to regard the force or the direction of the winds as not forming a sufficient explanation of the observed circulation of the ocean, suggested, as above stated, that differences of temperature must tend, by disturbing the equilibrium of the water, to cause a constant circulation between the equator and the poles ; and have by various theories endeavoured to explain the action of this effect in such a manner as to reconcile it with what is known of the actual circulation.[1] According to the most popular form in which the temperature theory has been propounded, polar cold causes the water to sink in those regions, and thence to travel along the bottom

[1] Maury, as a practical investigator, was compelled to abandon the idea of the circulation of the ocean being caused by the winds, and therefore turned his attention to the current-creating action of differences of temperature, but he has not attempted systematically to trace the connection between the observed effects and the suggested cause.

of the ocean to the equatorial regions, there to rise and return to the poles as surface water. Recent researches have, however, practically refuted that theory.[1]

Neither of the foregoing causes has, however, at any time obtained general acceptance among men practically acquainted with the movements of the

[1] The above paragraph has been added to this edition, and the manner in which the theory alluded to has already been refuted by recent researches, may be judged of by the following extracts:—

'From the drift of this disrupted ice we have fair evidence of a great bodily movement of the water northward; for it must be remembered that icebergs have been fallen in with in the entire circumference of the Southern Seas, and that they are pushed in the South Atlantic ocean as far as the 40th parallel of latitude; in the South Indian to the 45th parallel; and in the South Pacific to the 50th parallel.

'In the discussion of oceanic circulation, it has been assumed that water flows from Equatorial into Antarctic areas; there is no evidence, so far as I am aware, that warm surface water in the sense implied is found south of the 45th parallel.'—*Address to the British Association*, September 1876, by F. J. Evans, C.B., F.R.S., Captain R.N., and Her Majesty's Hydrographer.

The motion of icebergs, above alluded to, from the pole to the temperate zone is against the average direction of the winds.

'I have never seen, whether in the Atlantic, the Southern Sea, or the Pacific, the slightest ground for supposing that such a thing exists as a general vertical circulation of the water of the ocean depending upon difference of specific gravity.'—Professor Sir Wyville Thompson's *Report to the Admiralty*, December 5, 1875.

For further consideration of the above question see Chapter VII. of *The New Principles of Natural Philosophy*. As heat acts chiefly by creating differences of specific gravity, the above quotation from Sir Wyville Thompson shows that the connection between its action and the existing circulation is not easily to be traced.

ocean. Opinion has always been divided on the subject; and some investigators, considering that neither of the foregoing causes satisfactorily explains the observed circulation of the ocean, have attributed the ocean currents to the axial rotation of the earth, or have endeavoured to connect them with the tidal action of the sun and moon.

All the foregoing views appear to have forced themselves upon the consideration of practical investigators. But since the days of Newton, the generality of men most abstrusely acquainted with what are regarded as the higher branches of scientific knowledge, have absolutely rejected the tides and the earth's rotation from among the possible causes of ocean currents, considering their current-creating action incompatible with the accepted laws of motion.

The laws on which their philosophy is based thus compel those who understand and accept those 'laws of motion' to conclude that either the winds, or unequal specific gravity resulting from difference of temperature or otherwise, or those two causes combined, must necessarily in some manner explain the circulation of the ocean.

It is, however, evident that whatever may be the current-creating action of the forces above alluded to, the fact of the tides being clearly dependent on the apparent motions of the sun and moon, shows that a full solution of the movements of the ocean cannot be attained through the consideration of merely

local causes, but requires the study of cosmical laws. These we will therefore take into consideration first.

By the force of gravitation drawing towards the centre of the earth, the ocean is held down in the hollows of the earth's undulated surface, and kept from overwhelming what is at present dry land. The level of the ocean is not, however, determined solely by this direct force of the earth's gravitation; for it is well known that the spherical form which that force tends to cause is changed by the earth's axial rotation to an oblate spheroid. It is therefore evident that the ocean does not partake of the earth's rotation by any spontaneous tendency; but that it is dragged round by the surface on which it rests.[1] As this is an unchanging influence, unceasingly acting in the same manner, its effects naturally claim a careful consideration before attempting to unravel the intricacies of those resulting from ever-changing causes.[2] And it is well, before entering on a discus-

[1] In the *Treatise on Vis-Inertiæ* the question of the existence or non-existence of any action of that force in the ocean is treated as a question to be solved; whereas in this work the oblate spheroidal form of the earth is accepted as a sufficient demonstration of its action in the ocean and on the surface of the earth, leaving only the further amount and nature of that action to be ascertained.

[2] Not only is the tidal action of the sun and moon an ever-changing influence in respect to any given part of the ocean, but it is also very slight in comparison with the action of the earth's rotation; for the extreme effect of that tidal action is to cause, over a very limited area, a rise and fall of about 120 feet, whereas the earth's rotation maintains a constant difference of level

sion of effects resulting from the earth's motion, to commence by recalling to mind what our knowledge of that motion is.

It is only recently in the historical period that the fact of the earth being in motion at all has been clearly realised. Scarcely more than three hundred years ago its immobility was regarded as an obvious fact. That the position of the earth was fixed and unchanging was supposed to be demonstrated by the clear and simple evidence of the senses, and the idea of its being in motion was regarded as an offspring of intellectual aberration.

It is true that nearly two thousand years before the period just mentioned some keen observers of natural phenomena perceived that the earth was actually in motion;[1] but, though this truth was so

between the equator and the poles amounting to about thirteen miles; thus giving what may practically be regarded as an *à priori* demonstration of its paramount influence.

[1] 'It was the ancient opinion of not a few, in the earliest ages of philosophy, that the fixed stars stood immovable in the highest parts of the world; that under the fixed stars the planets were carried about the sun; that the earth, as one of the planets, described an annual course about the sun, while, by a diurnal motion, it was in the meantime revolved about its own axis; and that the sun, as the common fire which served to warm the whole, was fixed in the centre of the universe.

'This was the philosophy taught of old by Philolaus, Aristarchus of Samos, Plato in his riper years, and the whole sect of the Pythagoreans; and this was the judgment of Anaximander, more ancient than any of them; and of that wise king of the Romans, Numa Pompilius, who, as a symbol of the figure of the world, with the sun in the centre, erected a temple in honour of

long ago apparent to the bright genius of those ancient philosophers, it was at variance with the common sense of mankind, and was therefore discarded as a fanciful delusion until, in the sixteenth

Vesta, of a round form, and ordained perpetual fire to be kept in the middle of it.

'The Egyptians were early observers of the heavens; and from them, probably, this philosophy was spread abroad among other nations; for from them it was, and the nations about them, that the Greeks, a people of themselves more addicted to the study of philology than of nature, derived their first, as well as soundest notions of philosophy: and in the vestal ceremonies we may yet trace the ancient spirit of the Egyptians; for it was their way to deliver their mysteries, that is, their philosophy of things above the vulgar way of thinking, under the veil of religious rites and hieroglyphic symbols.

'It is not to be denied but that Anaxagoras, Democritus, and others, did now and then start up, who would have it that the earth possessed the centre of the world, and that the stars of all sorts were revolved towards the west about the earth, quiescent in the centre, some at swifter, others at a slower, rate.

'However, it was agreed on both sides that the motions of the celestial bodies were performed in spaces altogether free and void of resistance. The whim of solid orbs was of later date, introduced by Eudoxus, Calippus, and Aristotle; when the ancient philosophy began to decline, and to give place to the new prevailing fictions of the Greeks.'—Newton's *System of the World.*

It has been said that the Druidical ruins in Britain show that their builders knew of the true arrangement of the solar system; but, as far as I am aware, this idea is not supported by sufficiently reasonable arguments to allow of its being regarded as more than a vague conjecture. It must, however, be admitted that the ignorance which subsequently prevailed throughout the country is not a valid argument against antecedent knowledge; for we see that the degeneracy of knowledge in Rome was such, that the successors of Numa Pompilius imprisoned Galileo and others for asserting the truths which formed the basis of the ceremonies for the celebration of which the temple of Vesta, in the same city, was built by that 'wise king.'

century, Copernicus published his cosmical theory, maintaining that the earth rotates each day on its axis, and revolves each year round the sun.

Even then these views met with no ready acceptance. And after the publication of the theory of Copernicus, one of the greatest of philosophers, Descartes, was at great pains to explain how, when, in describing his system of the world, he spoke of the earth moving, he did so improperly, and only for the sake of simplifying the explanation of an hypothesis : and he argued that, even supposing his cosmical hypothesis to be true, even then, speaking in a proper sense, the earth did not really move.

These men, with Kepler, Galileo and others, paved the way for Newton, who, immediately after Descartes, enforced the theory of the axial rotation and orbital revolution of the earth with such clearness and precision that the belief in these motions gradually extended until they at length became generally accepted as incontrovertible facts.

These two motions of the earth, re-discovered by Copernicus—namely, the diurnal motion of rotation on its axis, and the motion by which it is annually revolved in its orbit round the sun, are the only great movements of the earth of which we have, even at the present day, a definite knowledge. But besides these motions, a third great movement was, towards the close of last century, pointed out by Sir William Herschel, who showed that not only is the

earth moving round the sun, but that the sun, carrying with it the earth and the whole solar system, is itself moving along among the fixed stars. But though astronomical observations have demonstrated the existence of this motion, neither its direction nor its velocity has been clearly defined ; and as regards any motion which the solar system may, for aught we know to the contrary, partake in common with the stellar system, the distance to which our range of vision has been extended by the telescope is not sufficient to enable us to obtain any direct information from the science of astronomy.[1]

[1] In the treatise on Vis-Inertiæ already alluded to, as also in this work, it is, however, shown that the evidences of the action of vis-inertiæ in the ocean indicate a motion of the earth southwards; and that the indications of the action of that force in the outer crust of the earth corroborate the evidence of the ocean currents. Those effects may be treated as if resulting from the motion of the solar system. For, the effects of motion as shown by tides, currents, and winds, will be the same whether those effects result simply from a motion of the solar system in the direction of the south pole, or be the average result of a motion of the solar system in the direction of the north pole combined with a motion of a more extensive system with a greater velocity in the opposite direction. That is to say, as far as the present question is concerned, those effects might either result from a motion of the solar system by which the earth is moved together with that system; sweeping along among the stars which compose the visible part of the universe, and so changing its position among those stars; or, they might be the result of a motion of the whole stellar system, in which the earth, the sun and the stars, equally partake as particles of that system; the motion demonstrated in the direction of the south pole being, in such case, a majestic movement in which the whole visible universe is travelling onwards in that direction.

For the elucidation of the effects of the motion of the earth, we have the well-known fact that whenever a vessel containing water is set in motion, the water which it contains has a tendency to move along its surface in the opposite direction to that in which it is moved.[1]

And, since astronomical observations appear to have shown that the solar system has a motion among the stars by which it is carried along in the direction of the northern hemisphere, we are, if those observations be reliable, compelled to the conclusion that in the same manner as that in which, when the moon is inside the earth's orbit, the lesser velocity of its orbital motion round the earth is lost in the greater velocity of the orbital motion in which, together with the earth, it is carried round the sun; so also, in a similar manner, must the velocity of the motion in which the solar system is carried northwards among the stars, be lost in the greater velocity of a motion in which, together with the stars, it is moving southwards.

[1] The argument of the *Treatise on Vis-Inertiæ* does not allow of this illustrative case being assumed to be analogous to that of the earth and its ocean; and though I have in the present work considered it reasonable to admit, as stated on page 4, that the oblate-spheroidal shape resulting from the earth's rotation is evidence of the conditions in the two cases being analogous, the demonstration required, as stated in the following extract from the first chapter of the above-mentioned treatise, is in fact given in this work also; and the Second Part of that demonstration has been given in much more detail in *The New Principles of Natural Philosophy*:—

'As we do not know in what manner the force which causes any known motion of the earth acts upon the earth, we cannot assume that by that motion any action of vis-inertiæ is brought into play in the ocean, but the very existence of such action is necessarily a subject for demonstration, and cannot logically be inferred or denied, by analogy, from any known phenomena.

'The subject, therefore, naturally divides itself into two parts.

'First, by theoretical deduction to demonstrate hypothetically the action of vis-inertiæ:

This is a simple law of nature :—though the vessel containing the water is set in motion, the water tends to maintain its position, and therefore has a relative motion over the surface of the vessel in the opposite direction to that in which the vessel is moved.

We need not immediately investigate the abstract nature of the force which tends to cause this relative motion of the water, for it is sufficient, as far as our present purposes are concerned, that it is a simple matter of fact that, in the case just mentioned, the water has a tendency to maintain its position ; and that therefore, when the vessel which contains it is moved, the force which tends to hold the water in that position tends also to cause it to move along the surface of the vessel in the opposite direction to that in which the vessel is moved ; and that this force—which indisputably does exist, be its abstract nature what it may—is termed vis-inertiæ.

In the consideration of the forces which keep the ocean in motion, we are, for the reasons given above, called on to give precedence to the action of this force of inertion, or vis-inertiæ.

'Secondly, by practical investigation to ascertain whether or not there exist in the ocean such movements as may, in the first part, be demonstrated to be the natural result of the action of vis-inertiæ.

'If the practical investigations show the existence of movements in the ocean clearly according with the theoretical deductions, we may then, in the absence of any other reasonable cause being adduced, conclude that vis-inertiæ is the cause of those movements.'

BOOK II.

EFFECTS OF THE MOTIONS OF THE EARTH.

THEORY OF OCEAN CURRENTS.

CHART

to illustrate the

CURRENT CREATING ACTION

OF THE

EARTH'S AXIAL ROTATION,

discarding the effects of onward motion, the Winds, differences of temperature, the tidal action of the Sun & Moon, and derangements caused by islands and mountain ridges below the surface of the ocean, except that, to illustrate the latter derangements, an island has been inserted in the North Pacific and another in the Antarctic Pacific District.

The blue arrows represent the surface currents O R. and E H. of Plate IX in each district, and the red arrows the analogous under currents. The volume of the main streams O.R. is immensely greater than that of the counter currents E.H. which latter are shown by dotted arrows. Excepting in the Antarctic Atlantic district, the existence of all the surface streams O.R. has been clearly proved by the recent explorations as also that of several of the counter currents E.H. and under currents O.R.

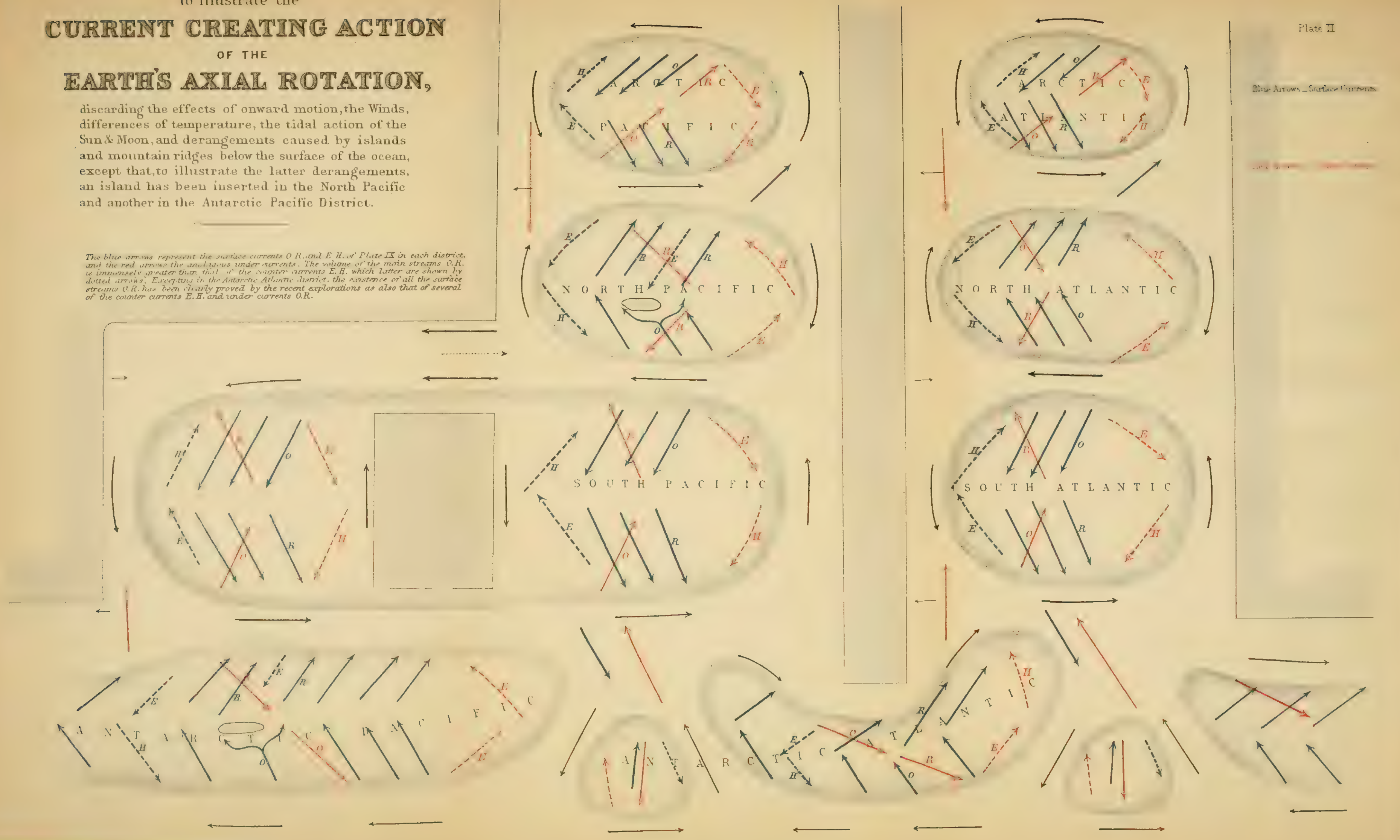

Plate II

Blue Arrows _ Surface Currents

CHAPTER II.

EFFECTS OF THE EARTH'S AXIAL ROTATION.

PART I.

GENERAL EFFECTS.

SINCE the motion of the earth's surface round its axis is from west to east, any existing action of vis-inertiæ must therefore, according to the foregoing illustration, tend to cause the water which lies on the surface to move along that surface from east to west. That is—a pressure is created acting in the opposite direction to that in which the surface of the earth is moving, giving the water a tendency to stream round the earth from east to west.

This westward pressure, imparted to the ocean by the rotation of the earth eastwards on its axis, is obviously a fixed and unchanging influence; for the earth is constantly rotating at the same rate and in the same direction round its axis of rotation.

And, since the speed at which the surface of the earth rotates at the equator is more than a thousand miles an hour and at the poles nothing, all intermediate gradations of speed lying evenly between the

equator and the poles, it is obvious that the force of westward pressure imparted to any given mass of water lying about the equator is greater than that imparted to an equal mass of water lying about the poles.

And also, since the velocity of rotation at the surface of the ocean is greater than at the bottom; therefore in all parts of the ocean the westward pressure imparted to the water at the surface is greater than that imparted to the water lying beneath it.

In order to illustrate the action of these unequal forces when brought into conflict, let it be observed that: if an ordinary globe be held by its stand and be, with a rapid motion, moved in a curve line in a plane at right angles to the axis of its poles, as from D to E in Plate III., then, if the onward motion be suddenly arrested, the globe will rotate on its axis; the axial rotation being in the direction A H B L.

This motion of rotation results from the inequality of the forces of onward impetus generated on the sides A and B by the movement of the globe in a curve line from D to E.

For the curve line A A is similar to, but greater than, the curve line B B: and, as the point A describes the curve line A A in the same time that the point B describes the curve line B B, therefore the velocity of the point A is greater than that of the point B; and, on the onward motion of the axis being arrested, the

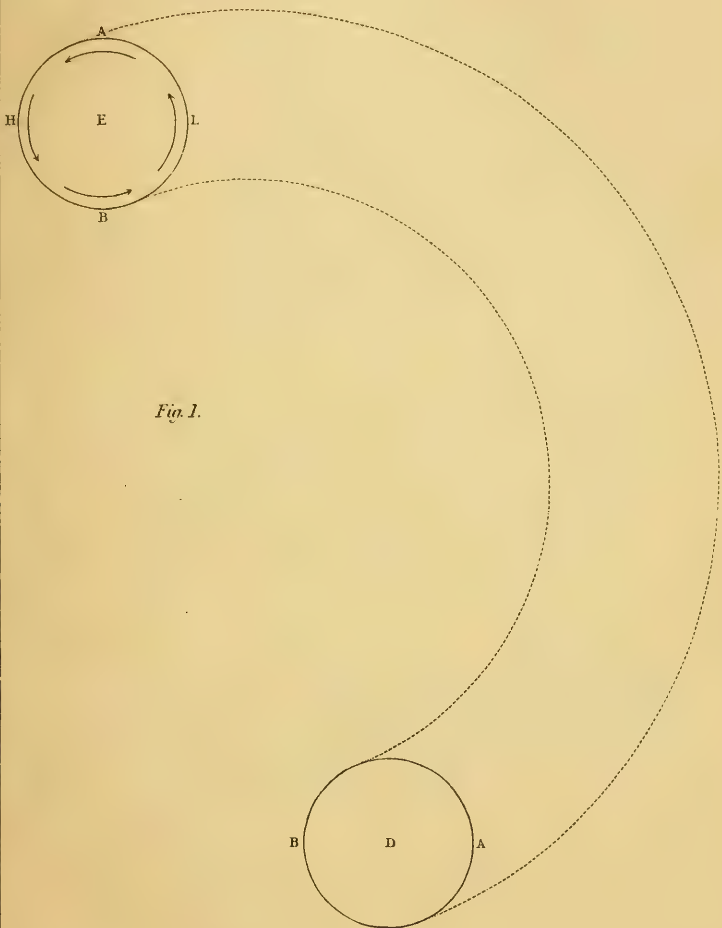

Fig. 1.

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momentum which has been generated by that motion tends to carry the point A round the axis in the direction A H B L; the momentum generated at the point B tending at the same time to carry the point B round the axis in the opposite direction, that is, in the direction B H A L. The forces generated on the sides A and B are thus brought into conflict: the lesser force, B, must of necessity yield more or less, in accordance with the relation which the opposing forces bear to each other: and thus the greater force of the side A imparts a motion of rotation to the globe in the direction A H B L.

Also: since in streams of water the greatest force is in the central parts of the streams; therefore, wherever a stream is obstructed, the greater force of the central part of the stream overwhelms the lesser forces on each side; so that the stream divides, branching off right and left from the point of obstruction.

And for the same reason, also, when two streams meet, there must be offsets branching off in opposite directions from the meeting-points.

In the case of the overwhelming of lesser forces by greater forces, exemplified above in connection with Plate III., the check to the onward motion is given at the central axis; so that the quantities of motion brought into conflict are of necessity unequal; for the masses of matter brought into conflict may,

as far as our present purposes are concerned, be considered equal in volume, and the velocity of one of those equal masses is greater than the velocity of the other.

But, in the case of a stream of water meeting with an obstruction in its course, where the different parts of the water are moved with unequal velocities; the check given to the onward motion which brings those unequal velocities into conflict, is not given as in Plate III. at a central axis, necessarily bringing a volume on one side of the axis into conflict with an equal volume on the other side, but this check is given at the end of each line of motion; so that, although unequal velocities are brought into conflict, yet, as far as the demonstration in connection with Plate III. is concerned, there might nevertheless be no overwhelming of lesser forces by greater forces; because, by a greater volume of the water moved at the lesser velocities opposing itself to a lesser volume of that moved at the greater velocities, the quantities of motion brought into opposition might be equalised; thereby preventing the overwhelming of lesser forces by greater forces in the manner demonstrated in connection with Plate III.

But that, though the onward motion of the fluid be checked at the end of each line of motion, there will nevertheless be an overwhelming of lesser forces by greater forces, may be demonstrated by holding a goblet containing water in an inclined position, as in

Fig. 1.

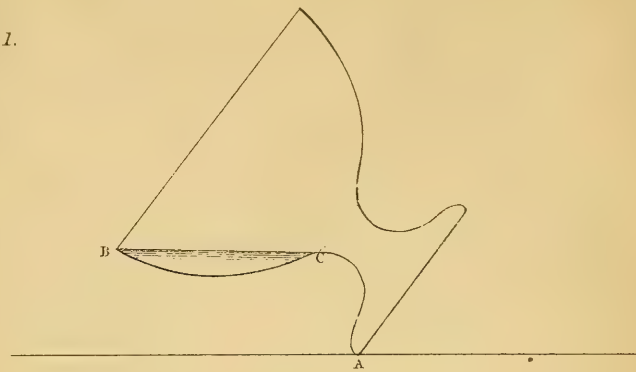

Fig 2.

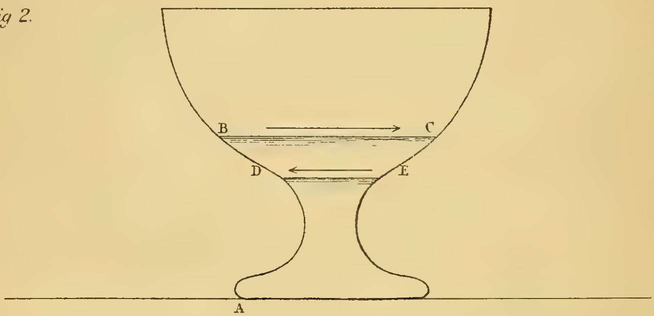

Fig. 3.

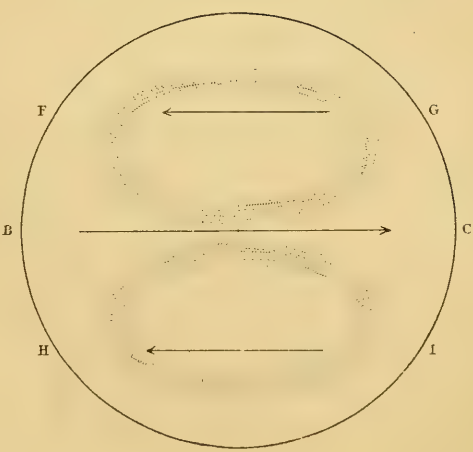

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Plate IV. figure 1, and then, with the point A as a pivot, bringing it into an upright position as in figure 2. In this case the central line of motion, B C, overwhelms the lines of lesser force, F G and H I in figure 3, on each side; and sets the fluid in motion in the directions B C G F B and B C I H B. And also, the surface line of motion, B C, overwhelms the line of lesser force, D E, in figure 2, at the bottom of the fluid; causing a motion in the direction B C E D B. It is then evident that where unequal forces are brought into conflict the lesser force must yield. And we have seen that the force of westward pressure is greater in equatorial than in polar regions; and also greater at the surface than at the bottom of the ocean. These inequalities in the force of westward pressure result from the inequalities in the velocity of rotation in those parts of the ocean. And we will now consider how these unequal forces are brought into conflict, and what movements result from their conflicting action.

This westward pressure would obviously give the water a tendency to change its meridian westwards by the shortest route; that is, to make as much westing as possible in any given space traversed. And, as the earth's equatorial diameter is greater than its polar diameter, this shortest route westwards is not in lines running due west, but in lines diverging from the equator somewhat northwards and

southwards. This divergence from the equator implies a change of latitude: therefore a tendency to cause a change of latitude is an attribute of westward pressure.

And change of latitude has itself two important attributes whose action in the atmosphere was clearly recognised by George Hadley as affecting the course of the Trade Winds; but whose action in the ocean appears to have been first pointed out by Captain Maury, as affecting the course of the Gulf Stream: that is, that a tendency to change of meridian eastwards is an attribute of such change of latitude as causes an increase of equatorial distance; and that a tendency to change of meridian westwards is an attribute of such change of latitude as causes a decrease of equatorial distance.

For, since the velocity with which the surface of the earth rotates at the equator is upwards of a thousand miles an hour and at the poles nothing, therefore, in any change of latitude in a direction leading from the equator towards either of the poles, that which changes its latitude has a faster eastward momentum than that which belongs to the latitude into which it enters, and will consequently have a tendency to change its meridian eastwards. Whereas in any change of latitude in a direction leading from the poles towards the equator, that which changes its latitude has not so fast an eastward momentum as that which belongs to the latitude into which it

enters, and it will consequently have a tendency to change its meridian westwards.

In the former case, that which changes its latitude rushes on in advance of the latitude entered; and in the latter case, the latitude entered rushes on in advance of that which enters it. The former may be called a tendency to run eastwards, and the latter a tendency to fall westwards.

The change eastwards is in fact a tendency of the water to part from, or run on in advance of, a surface of less velocity; and the change westwards, a falling of the water against a surface of greater velocity with which the change of latitude brings it into contact.[1]

[1] It is greatly to be regretted that it has become customary to use terms, in reference to the direction of ocean currents, in exactly the opposite sense to that in which the same terms are used in reference to the winds. This custom is so firmly established that, as the advantages to be gained by altering it are not perhaps sufficient to repay the temporary confusion consequent on a change in the use of terms, the idea of changing the custom cannot perhaps be entertained; though a judicious use of terms has more to do with the progress of any science, than is perhaps generally supposed. In speaking of the wind, the terms used denote the direction from which the wind blows; whereas, in speaking of ocean currents, the terms used denote, not the direction *from* which the current runs, but that *towards* which it runs. Thus an *easterly wind* denotes a wind running from east to west, but in the ocean an *easterly current* denotes a current running from west to east. In order, in some measure, to obviate the confusion which this injudicious use of terms tends to cause, I have invariably used the termination '*ward*' instead of '*ly*,' in reference to ocean currents, so that as an *easterly wind* denotes a wind running *from* the east, an *eastward current* denotes a current running *towards* the east. The ordinary use of these terms has been so confused, and their relative meanings so

PART II.

EFFECTS IN AN OCEAN COVERING THE EARTH.

Let us now consider the action of a westward pressure of the nature we have described, if acting in an unbroken expanse of water covering the surface of the earth and unobstructed anywhere by land.

Its tendency is to set the water in motion from east to west. And we have shown that the water thus set in motion tends to diverge from the equator on both sides.

If there be no obstruction in its course, this tendency to diverge will be equal at all points of the equator.

But it is clear that no stream can diverge from the equator unless a supply be brought to the equator. There cannot at any point be diverging streams unless at some other point there be converging streams. And if the diverging tendency be equal on every meridian, there is no reason why any one meridian should yield rather than any other. And therefore, unless it be possible to obtain a supply for diverging streams by some other means than the yielding of the diverging tendencies of one meridian

ill-defined even by the best authorities, that the distinction which I have here made does not interfere with any previous definition of their relative significations.

For the sake of further distinction and clearness in the use of terms, I have used the termination 'wards' instead of 'ward' when referring adverbially to the course of the currents.

for the supply of those of another, the streams must run due west right round the world in every latitude. In such case westward pressure would be acting due west in all parts of the ocean, and none of its attributes would be brought into play.

Since, however, we have shown that lesser forces must yield to greater forces, and, since the force of westward pressure is greater at the surface than at the bottom of the ocean, therefore, though no one meridian will yield to any other, the diverging tendency of the lower strata of water must yield on every meridian to the greater force of the upper strata; so that the lower strata would consist of converging streams, which, at the point of convergence, must rise upwards to supply the diverging streams of the upper strata.

Thus in the lower strata converging streams would be running towards the equator at all points from the north-east and south-east, and in the upper strata diverging streams would be running from all points of the equator towards the north-west and south-west.

It is clear that the streams of the upper strata must supply those of the lower. Let us consider what course they must pursue between their departure from and their return to the equator.

It is obvious that the streams of the upper strata, running from the equator at all points, must, as they proceed on their course, become compressed in con-

sequence of the decrease in the circumference of the earth in the latitudes which they are simultaneously entering. Now, as far as the forces at present under consideration are concerned, there is no reason why the stream on any one meridian should yield rather than that on any other meridian ; and therefore, the only manner in which the course from the equator could be continued would be by an increase in either the depth or the velocity of the strata in inverse proportion to the decrease in the circumferences of the consecutive latitudes. But gravitation will obviously prevent an increase of depth more than sufficient to carry the streams onwards a moderate distance beyond the latitude at which compression commences ; and that tendency to run eastwards, which increases in proportion with any increase of velocity, will just as obviously prevent the increase in the velocity of their course from the equator which would be necessary to carry the whole volume of the streams onwards towards the poles. And therefore, since there cannot be either an increase of depth, or an increase of velocity sufficient to carry the streams onwards towards the poles, and since the stream on any one meridian will not yield to allow of that on any other meridian proceeding, the pole-ward course of the upper strata must cease equally on every meridian. The streams of the upper strata must gradually descend on every meridian into the lower strata, where, on reaching the surface of the

earth, they must divide in opposite directions. The one division in each hemisphere will obviously form the streams which in the lower strata run towards the equator at all points from the north-east and south-east; and the other division in each hemisphere, turned towards the poles, being under that influence of change of latitude which tends to carry it eastwards, forms streams in the lower strata flowing through the temperate zones, and curving eastwards in their course towards the poles—that is, forming currents running from south-west towards north-east in the northern hemisphere, and from north-west to south-east in the southern hemisphere.

Now it is clear that the decreasing circumference of the earth must sooner or later act upon these streams running from the temperate zones towards the poles in the lower strata, in the same manner as upon the streams running from the equator towards the poles in the upper strata, and therefore they must gradually, having no other means of progressing, turn upwards into the upper strata, through which they must return southwards, until, meeting with the streams flowing from the equator in that upper strata, they form complete circuits of rotation between the temperate zones and the poles—the streams of the lower strata running eastwards in their course towards the poles, and those in the upper strata running westwards in their course from the poles.

Thus there would be formed two great zones of currents in each hemisphere, as shown on Plate V., in which figure 1 represents the currents of the upper strata, and figure 2 those of the under strata.[1]

The under strata in the equatorial zone run towards the equator at all points from north-east and south-east; and in each polar zone run towards the pole from south-west in the northern, and from north-west in the southern hemisphere.

And in the upper strata, the great westward current of the equatorial zone diverges from the equator on both sides; the diverging streams tending in their course more and more directly towards the poles, and then eastwards, until meeting with the streams running from north-east in the north polar zone and from south-east in the south polar zone.

PART III.

EFFECTS IN AN OCEAN SURROUNDED BY LAND.

Section I.—*Equatorial and Polar Districts.*

The course of the currents just described is that which would result from the action of westward pressure if acting in an ocean covering the surface of the earth and unobstructed anywhere by land.

[1] This circulation is demonstrated by a shorter mathematical argument in Chapter III. of *The New Principles of Natural Philosophy*; which does not, however, so well serve as a basis for the subsequent details. See also, farther on in this volume, Chapter XXI., Proposition XXVII.

Fig. 1.

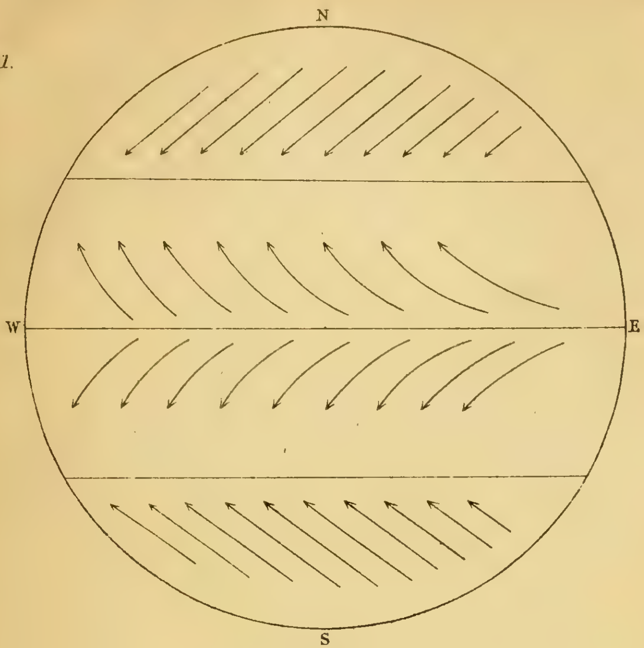

Fig. 2.

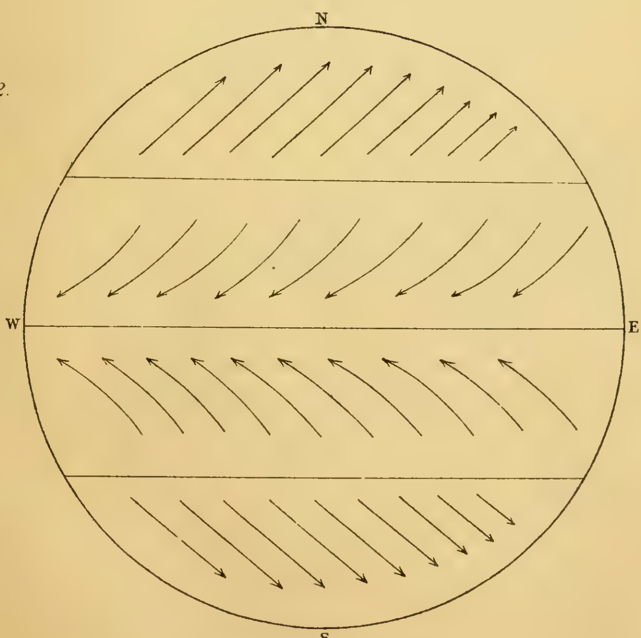

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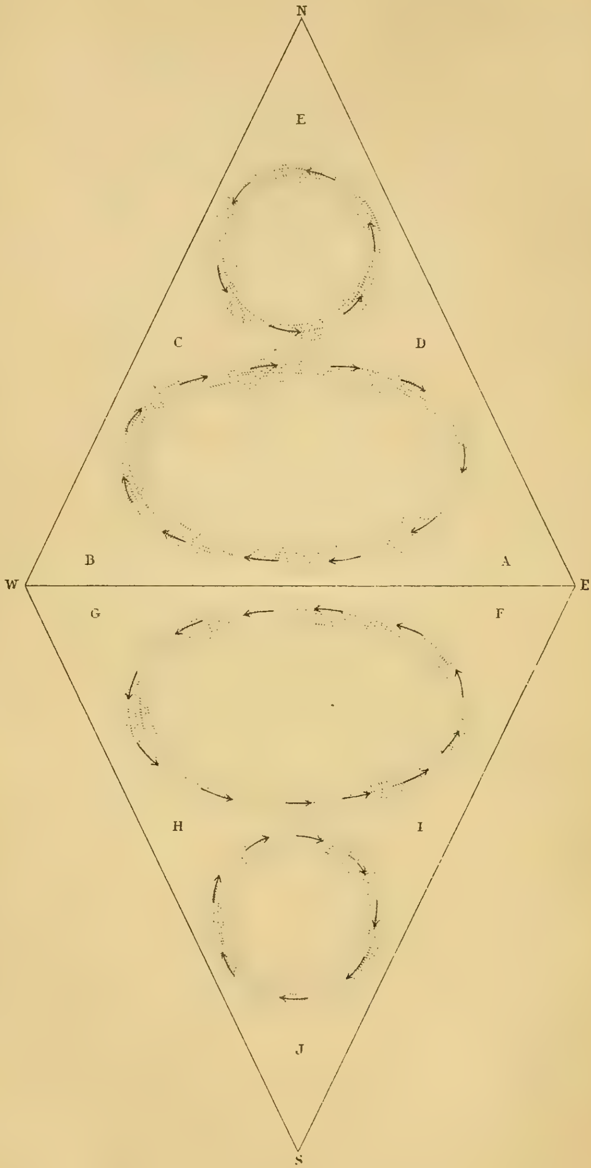
Plate VI.



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We will now, before applying its action to the ocean as it actually exists, consider its effects if acting in an ocean running north and south from pole to pole, and bounded east and west by an unbroken barrier of land. And we will first consider the effects resulting in such an ocean from the obstruction formed by the barrier of land, apart from the effects resulting from the difference in the relative forces at the surface and bottom of the ocean, and also all effects of friction.

Let N W S E, in Plate VI., be such an ocean as above described, E W the line of the equator, N the north pole, and S the south pole.

Now, if the forces of westward pressure were equal on each parallel of latitude, it is obvious that the only effect which could result from its action would be a change in the position of the water—that is, the level of the ocean would be depressed on the eastern and raised on the western side of the ocean.

Since, however, the force of westward pressure is greatest at the equator, and decreases from the equator towards the poles in proportion with the decreasing circumference of the parallels of latitude, and since lesser forces must yield to greater forces; therefore, the force of westward pressure created in the equatorial regions must overwhelm the lesser forces north and south, and drive the water eastwards through latitudes at some certain distance from the

equator on both sides. And this water, by returning to the equator from the north and south on the eastern side of the ocean, would form a supply for the greater force of westward pressure about the equator.

Thus the waters of the ocean would be set in motion westwards in the equatorial regions; northwards and southwards from the equator towards the temperate zones on the western side of the ocean; eastwards through the temperate zones; and from the temperate zones towards the equator on the eastern side of the ocean.

The action of westward pressure, under consideration, would not, however, simply tend to form these two revolving currents—one lying on each side of the equator; for, the water turned northwards and southwards from the equator on the western side of the ocean, comes under the influence of change of latitude, which, as it is increasing its equatorial distance, gives it a tendency to run eastwards; and therefore, instead of sweeping from the equator all along the western coast, and then back to the equator along the eastern coast, it must, at some certain distance from the equator, diverge eastwards from the western coast and flow through the ocean to strike upon the eastern coast. Dividing upon the eastern coast, one portion in each hemisphere forms the stream running from each temperate zone towards the equator; and the remainder in each hemisphere is turned along the eastern coast from each of the

temperate zones towards the poles. These streams on the eastern side of the ocean, flowing from the temperate zones towards the poles, are under that influence of change of latitude which tends to carry them eastwards, and they must therefore tend to follow the course of the coast, until, after sweeping through the polar regions, they appear on the western side of the ocean as streams flowing from the poles towards the equator. And as on the western coast, flowing towards the equator, they come under that influence of change of latitude which tends to carry them westwards, they must therefore tend to follow the course of the western coast, until they meet the streams flowing from the equator on that coast. Thus the streams turned polewards from the temperate zones, on the east side of the ocean, rejoin their parent streams on the west side of the ocean, forming continuous streams encircling each of the polar districts of the ocean. And thus, therefore, the ocean is divided, as far as its currents are concerned, into four separate districts, each encircled by a revolving current—an equatorial and a polar district being formed on each side of the equator, as shown in Plate VI.

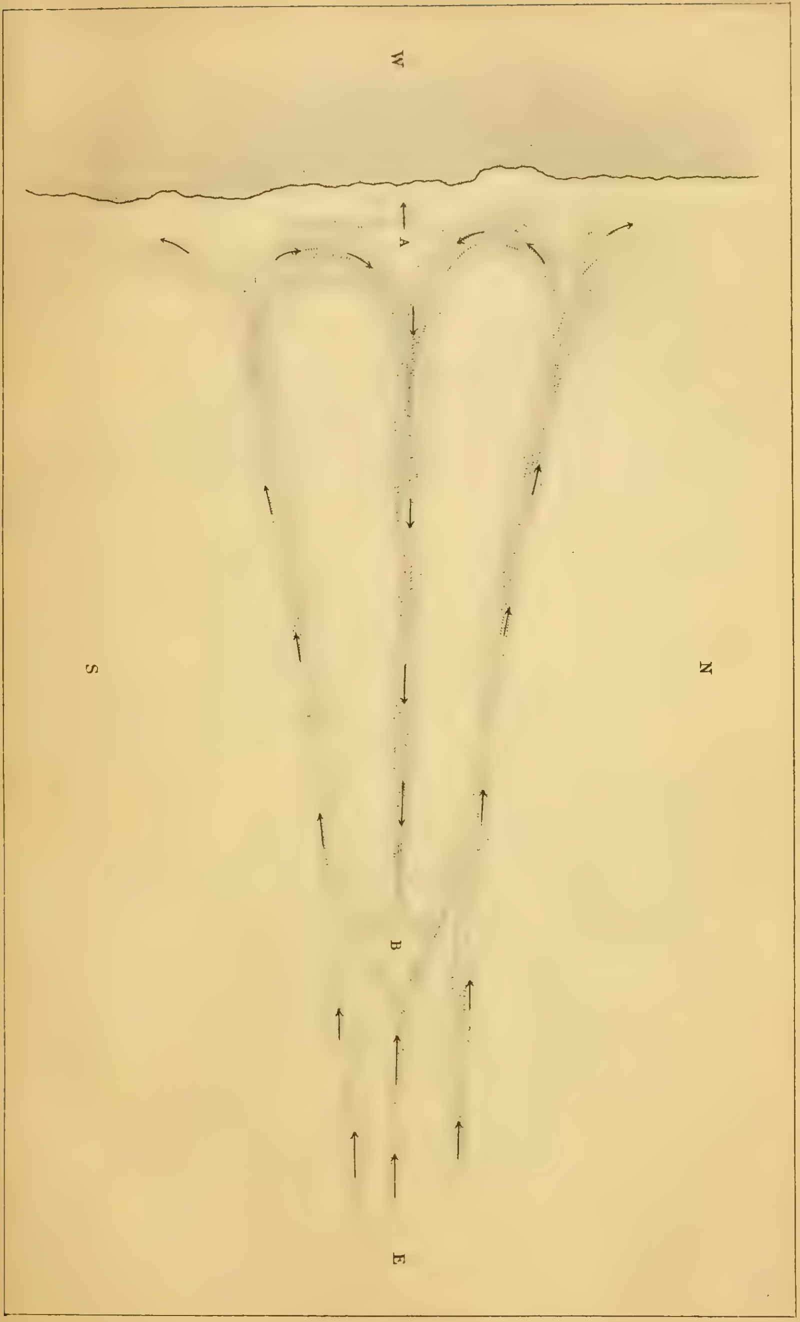
SECTION II.—*Equatorial Counter-Currents.*

We have, however, as yet, in this ocean, applied only that action of westward pressure which results from the difference in the relative forces of that

pressure acting along the different parallels of latitude, leaving out of consideration altogether the difference between the forces acting at the surface and at the bottom of the ocean. Let us now consider the effects of the opposing action of these latter unequal forces. Their tendency is to cause the great westward stream in the equatorial regions to diverge from the equator on both sides; and therefore, that stream may be considered as consisting of two separate portions, the one tending to run westwards and northwards, the other westwards and southwards. And, therefore, on meeting with the obstruction on the western side of the ocean, it is in fact not one stream but two streams; each of which streams must, on meeting with the obstruction, divide to the right and left; so that the left-hand division of the northern and right-hand division of the southern stream would meet and turn each other back eastwards, as shown in Plate VII. And this current running from west to east would, for whatever distance it might run, divide the northern from the southern portion of the great equatorial current running from east to west, and would to some extent supply the diverging tendencies of that stream.

Thus the inequality between the forces of the upper and under strata tends to cause a counter-current to run eastwards, dividing the north from the south equatorial district.

Plate VII.



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SECTION III.—*Inclination of the Axis of Rotation.*

But it is clear that the effects resulting from the inequality between the forces of the upper and under strata cannot possibly be such as to tend in any way to obliterate or even to change the positions of the districts shown in Plate VI. and just described in this chapter ; for those districts are precisely analogous to those which would be formed by a system of upper and under currents if westward pressure were not deflected by obstructions lying in its course. That is to say, they are analogous to the polar and equatorial zones described in the second part of this chapter and illustrated in Plate V. Those zones result from a necessary overwhelming of the lesser forces of the lower strata by the greater forces of the upper strata, in case of no obstruction occurring to deflect westward pressure from its natural course. And, in fact, since the deflection of that pressure does not change the relation of the forces of the upper and lower strata to each other, therefore the fact of westward pressure being deflected by the obstruction formed by coast-lines will not obviate the necessity of an overwhelming, to a greater or lesser extent, of the lesser forces of the lower strata by the greater forces of the upper strata ; and there must therefore be formed, notwithstanding the deflection of westward pressure, in every ocean, a system of upper and under currents analogous to

that exemplified in Plate V. And, since the deflection of westward pressure by coast-lines must cause an overwhelming of the lesser forces of the polar regions by the greater force of the equatorial regions, there must therefore, in every ocean, be a combination of these two systems of circulation. That is to say, there must be a horizontal circulation resulting from the overwhelming of the forces of the polar regions by the force of the equatorial regions; and also a vertical circulation resulting from the overwhelming of the force of the lower strata by the force of the upper strata. As the one system tends to cause each district to rotate round a vertical axis, and the other system tends to cause it to rotate round a horizontal axis, their combined action must cause it to rotate round an inclined axis; and the inclination of this axis will incline more towards either a vertical or a horizontal line, according as the relative force of the one or the other system of circulation may preponderate in any district. Since the currents west of the vertical axes conform to those above the horizontal axes, and the currents east of the vertical axes conform to those below the horizontal axes, the inclination of the axes resulting from their combined action must therefore be from west at the bottom of the ocean to east at the surface, as shown in Plate VIII. And, in this inclined circulation, since the ocean must preserve its level, the inclination of the axes necessitates an elongation of

Fig. 1.

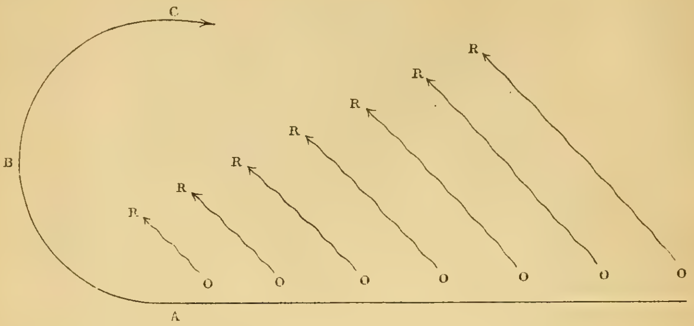
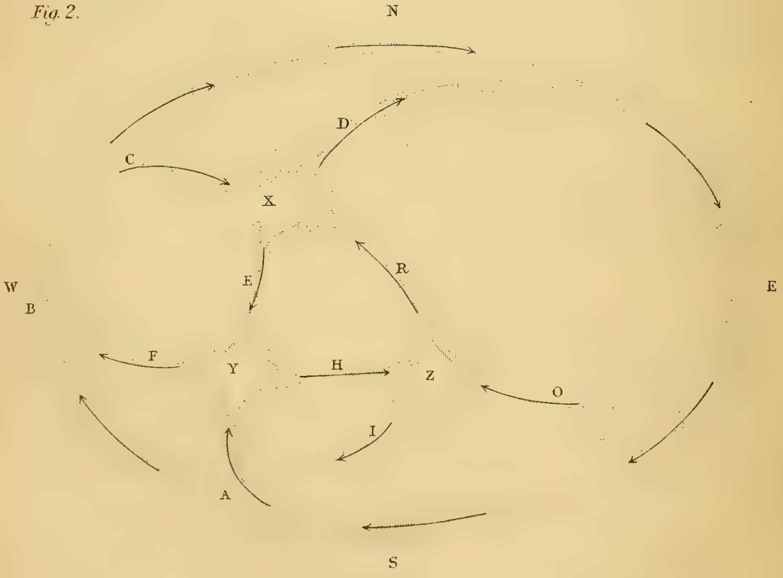


Fig. 2.



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the circles of rotation in the direction in which the axes are inclined. And, since this inclination of the axes is from west at the bottom of the ocean to east at the surface ; therefore, the elongation of the circles of rotation is westwards from the axes at the surface of the ocean, and eastwards from the axes at the bottom of the ocean. And thus, instead of the circles of rotation resulting from either the horizontal or the vertical forces, their combined action causes the revolving currents enclosing each district to tend to describe ellipses of rotation.

It thus appears that, setting aside the contortions caused by coast-lines, the combined action of the forces of vertical and horizontal circulation gives the currents which encircle each district a natural tendency to revolve in elliptical courses.

SECTION IV.—*Surface Currents within the Districts.*

Let us now consider how the combined action of these forces will affect the surface currents contained within each district.

Let N W S E, in Plate IX., figure 2, be a north equatorial district.

Under the sole influence of the horizontal circulation, the currents would all simply describe concentric circles of rotation round a central axis.

And, under the sole influence of the vertical circulation, the entire surface of the district would consist solely of currents running in parallel lines

from the equator; the circles of rotation being completed by under currents flowing towards the equator.

But, under the combined action of the forces which tend to cause these systems of circulation, the water which on the west of the district is turned from the equator by the horizontal force, necessarily comes into conflict with that tending to diverge all along the line of the equator under the action of the vertical force. The streams O R, in figure 1, diverging under the action of the vertical force, must then be borne back by that under the action of the horizontal force A B C, until, by the accumulation of the streams O R, they form a stream equal in force to A B C.

Let the point X, in figure 2, be the meeting-point of the opposing streams thus formed.

Then the stream A B C meets the stream O R at X; and from the meeting-point at X the offset D falls into the course of the rotation of the district S W N E; but the offset E, running in the opposite direction, must come into conflict with that course of circulation.

Let Y be the point at which the stream E meets the stream S W N E.

Then from the meeting at Y the offset F falls into the course of rotation S W N E; but the offset H, running in the opposite direction, must come into conflict with the course of rotation S W N E.

Let Z be the point at which the stream H meets the stream S W N E.

Then from the meeting at Z the offset I falls into the course of rotation S W N E; and the offset R falls into the course of the stream O R, forming an unbroken course of circulation, which may be termed the natural course of the surface currents within each district.

Since the streams A B C and O R both tend eastwards in their course from the equator, and the stream E H tends westwards in its course to the equator, the latter must, sooner or later, after leaving the point X, be thrown against the stream A B C, and then be forced eastwards, running counter to that stream as far as the point at which the stream O R diverges from it.

SECTION V.—*Vertical Circulation within the Districts.*

Now the axis of this district being inclined as before described, it is clear that about the central parts of the district an under current must be running southwards, whilst the surface above it is flowing northwards. Let us consider how this is effected. The point X (Plate IX., figure 2), as already described, is that at which the opposing streams A B C and O R meet with equal force as surface currents.

But, since the stream A B C is that which is deflected by the coast-line, which deflects the whole mass of water from the surface to the bottom of the

ocean; whereas the stream O R results from the yielding of the lesser force of the lower strata to the greater force of the diverging tendency of the upper strata; therefore, although at the surface of the ocean the stream A B C is effectually resisted by the stream O R, it will nevertheless meet with no such resistance in the lower strata; but, in proportion as the force of the stream O R diminishes beneath the surface, it will be underrun by the stream A B C; and at the bottom of the ocean, not only will the stream A B C meet with no resistance from O R, but under the action of the vertical forces of circulation, its southward course as an under current will be accelerated until it completely underruns O R, and reappears at the surface in the equatorial regions.

Section VI.—*Under-Currents within the Districts.*

Thus, whilst opposing the stream O R on the surface of the ocean, the stream A B C joins the course of the streams flowing towards the equator at the bottom of the ocean. But though A B C joins the course of those streams at the bottom of the ocean, they are thrust away by it from the western part of the district just as the streams O R are on the surface; and therefore by this conflicting action a counter-current must be formed at the bottom of the ocean, running counter to the stream N E S W, under the axis of rotation inversely as E H runs counter to it on the surface.

SECTION VII.—*Difference in the Action of Counter-Currents in Equatorial and Polar Districts.*

The conflicting action of the forces of vertical and horizontal circulation in the polar districts must tend to form counter-currents analogous to those of the equatorial districts; but in them those currents will tend to run against the central streams instead of against that which encircles the district.

SECTION VIII.—*Connecting Currents between Equatorial and Polar Districts.*

Referring to Plate VI., it will be seen that the equatorial stream A B C meets a polar stream pouring down upon it from the north in the neighbourhood of C; so that, in fact, as the stream A B C opposes O R on one side, it also opposes the polar stream E C (Plate VI.) flowing from the opposite direction on the other side. The southward course of the polar stream E C (Plate VI.) is obstructed on the surface of the ocean by the equatorial stream A B C; but we have seen that, in consequence of the action of the vertical force of circulation, the equatorial stream A B C offers no obstruction to the southward course of the polar stream in the lower strata. The lower strata of the polar stream E C (Plate VI.) must therefore continue their course southwards as an under current; to some extent joining the lower strata of the stream A B C as it underruns the course of the surface stream O R, in the opposite direction, and

rising to the surface in the equatorial regions under the action of the force of vertical circulation; which latter necessitates a circulation from the equator at the surface and towards the equator at the bottom of the ocean in the central parts of the district S W N E, in Plate IX., just as the horizontal force necessitates a circulation from the equator on the west and towards the equator on the east side of the district.

Thus a constant circulation between the equatorial and polar regions is caused, for as the polar stream E C D is carried southwards, displacing the stream A B C in the lower strata, an equal volume of the stream A B C must be thrown into the course of the stream C D E in the upper strata.

Section IX.—*Subdivision of Districts.*

The course of the currents which we have described in connection with Plate IX. we have termed the natural course of the currents within the district; but in fact it is clear that instead of the horizontal force of circulation being contained in one stream and meeting the vertical force, also in one stream, as at X, there might, by the horizontal force being partially deflected by obstructions in its course before reaching the west side of the ocean, be many such meeting-points formed within a district, all being nevertheless of a similar nature: but, since the number of these meeting-points in any district must be determined by the configuration of the coast-lines

and bottom of the ocean, this is a question to be considered in the practical investigation of the movements of the ocean.

PART IV.

EFFECTS IN THE OCEAN AS IT IS.

In the actual configuration of land and water on the surface of the earth, there are, as far as westward pressure is concerned, two great force-creating regions in the ocean—one the equatorial region of the Atlantic, the other that of the Pacific and Indian Oceans. The Pacific and Indian Oceans, being connected in the force-creating regions, must be regarded as subdivisions of the same district: and, as pointed out in the preceding part of this chapter, barriers of islands, or ridges over which the water is comparatively shallow, form other subdivisions, theorectically similar, though not so distinctly marked as that which forms the Indian Ocean.

In the northern hemisphere, the comparatively unimportant opening of Behring's Strait being the only communication between the Pacific and Atlantic Oceans, we have two oceans which, as shown in the chart on Plate II., should each contain an equatorial and a polar district of currents analogous to those whose formation has been described in Part III. of this chapter, and illustrated in Plate VI.

The basin of the Arctic Ocean thus forms a part of the Arctic district of the Atlantic Ocean: and, therefore, the stream which on the eastern side of the Atlantic flows northwards from the temperate zone enters the Arctic Ocean on the eastern side of the Atlantic, and flows from the Arctic Ocean on the western side of the Atlantic. And, in consequence of the inclination of the axis of the district before explained, the stream which enters the Arctic Ocean passes under the axis, and that which flows from the Arctic Ocean passes over the axis; and therefore, all along the coast which lies east of the entrance from the Atlantic to the Arctic Ocean, the surface water sets from the coast; and, all along the coast which lies to the west, the surface water sets against the coast: this is so because the stream which enters the Arctic Ocean is naturally an under current, and is forced to the surface by the obstruction formed by coast-lines, as shown in Plate X.

In the southern hemisphere the oceans communicate freely through the comparatively wide and deep expanse of water lying between Cape Horn and the South Shetlands in the one direction, and in the other direction the communication beyond the tropics is still more free. Besides this, there is a vast extent of earth's surface in high southern latitudes which has not yet been explored, and which may therefore, as far as our knowledge from actual observation is concerned, consist of either land or water. Since,

How about drift of [illegible]
from Behring Sts.

Note.

The normal circulation of the polar regions which the Earth's rotation tends to cause is north eastwards towards the pole in the under strata and south westwards from the pole on the surface of the ocean. But the chart was drawn in 1866 on the supposition that the flow of water northwards from the Atlantic in the under strata, not meeting an equal flow towards the pole from the opposite direction, flows onwards to rise to the surface against the northern shores of Asia, and the red and blue arrows have now 1877 been added in accordance with that supposition, the extent to which the normal circulation of the polar region is deranged by the preponderance of the influx of water from the Atlantic side is a question to be determined by practical observation. The letters refer to Plates IX and II the red being under currents, and the blue surface currents, as in the latter Plate.

The normal surface pressure from the north east may be the preponderating force in higher latitudes than have yet been explored, but it is not the preponderating force in the Arctic Ocean, for it tends to carry the ice of the Palæocrystic Sea westwards.

however, the Antarctic voyages of discovery under Sir James Ross and Captain Wilkes have shown the existence of a considerable tract of land in high southern latitudes, I will proceed with this theoretical consideration of the action of vis-inertiæ under the supposition of an Antarctic Continent of considerable extent existing in the south polar regions.

Let the streams marked Atlantic and Pacific in Plate XI*a*. be streams flowing towards the Antarctic Continent E, from separate equatorial regions. These streams have a tendency to run eastwards in their course from the equator towards the pole. In their course towards the pole they are obstructed by the continent E. On meeting with this obstruction, each stream must divide right and left; one portion of each stream being turned westwards, and the other portion of each eastwards. The westward division of each stream must, as it flows on its course, meet the eastward division of the other stream: so that the Atlantic and Pacific streams meet each other in both directions on opposite sides of the Antarctic Continent. From each of these meeting-points, the streams must branch off in opposite directions: so that one branch from each meeting-point must fall against the Antarctic Continent, and the other branch from each of the two meeting-points must flow northwards towards the equator.

Let any points A and B, on opposite sides of the

Antarctic Continent, be the points at which the Atlantic and Pacific streams meet.

Then in each ocean a stream flowing southwards and eastwards from the equatorial regions meets a stream flowing westwards and northwards from the polar regions, as shown in the plate : and, from the meeting-point in each ocean, one branch flows northwards towards the equator, and the other branch sweeps the shores of the Antarctic Continent, and then forms the stream which flows westwards and northwards from the polar regions in the opposite ocean.

The Antarctic Continent must cause a subdivision of each of the Antarctic districts as shown in Plates XI. and XI*a*., because the stream turned south from each meeting-point must redivide on striking the Ant arctic coast, and then the portions turned eastwards must recoil upon their parent streams, forming separate districts of rotation ; and forming also, at the points C and D at which they meet the parent streams, an interlacing of currents with revolving fragments similar to that which occurs where a polar stream rejoins the equatorial stream from which it has its source, as at F and G.

The meetings at A and B are meetings of independent streams, from separate force-creating regions, and therefore they mutually repel each other until an equilibrium of force is established between them. But the meetings at C, D, F, and G are formed by the

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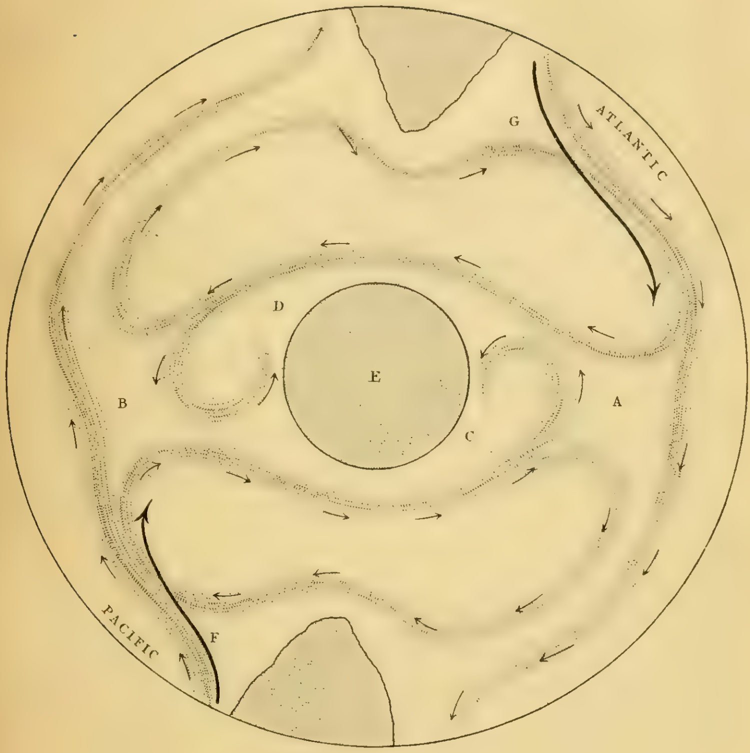
recoiling of branch streams upon the parent streams, through which they derive the force which keeps them in motion; and each of the branch streams must therefore, as far as the action of the horizontal force of circulation is concerned, be gradually redrawn into the course of its parent stream through a series of rebounds against it.

From the arguments contained in this chapter, it appears that, as far as the currents resulting from axial rotation are concerned, the ocean is divided into two divisions: the one division consisting of currents which are kept in motion by force created in the equatorial regions of the Atlantic Ocean; the other, of currents which are kept in motion by force created in the equatorial regions of the Pacific and Indian Oceans. And these divisions being analogous to each other—each being subdivided into equatorial and polar districts analogous to each other—form together the ten principal districts shown in the chart on Plate II.: namely—

Two North Equatorial,
Two South Equatorial,
Two Arctic, and
Four Antarctic districts.

This subdivision of the Antarctic districts depends, as before stated, on the existence of an Antarctic Continent about the south pole. And I have described the action of vis-inertiæ in those regions under this supposition, because the information gained

in the voyages of discovery already alluded to, and also the actual currents, as far as their course has been ascertained, appears to be in accordance with it. The correctness of this is, however, a question to be determined in the practical investigation of the subject.



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CHAPTER III.

EFFECTS OF THE EARTH'S ONWARD MOTION.

PART I.

EFFECTS OF ORBITAL MOTION.

According to the foregoing the action of vis-inertiæ in causing currents results from inequality of opposing forces; and therefore, as regards the orbital motion of the earth, since its velocity is the same at all parts of the earth, it is obvious that its action in causing currents can result only from the greater facility with which water yields to the action of vis-inertiæ in one part of the ocean than in another part. And, that the water tends to yield more readily in some parts of the ocean than in others to the action of any force which may tend to set it in motion, may be illustrated by the well-known phenomenon that in any river or stream the water at the surface of the deep and central parts tends to move more rapidly than that in shore or at the bottom of the stream; because the friction of the ground over which it runs checks the progress of the water, leaving that at the surface of the deep and central parts of the stream comparatively free to run its

course under the action of the force of gravitation. This force of gravitation acts with equal force upon all the particles of the stream, but those at the sides and bottom of the stream are checked by friction, which is therefore a force acting in opposition to that force of gravitation which tends to draw the stream onwards; and it is because the particles at the surface of the deep and central parts of the stream are comparatively free from the opposing action of this friction that they are drawn onwards more rapidly by the force which impels the stream on its course. We need not here investigate the abstract nature of the force which causes the particles near the sides or bottom to resist more than those at the surface of the deep and central parts of the stream, the force which tends to set them equally in motion. We are here only concerned with the fact that it is a force which opposes the action of any force which may tend to set the water in motion. It is for the present sufficient that the force described as friction tends at the sides and bottom of the ocean to check the action of vis-inertiæ in those parts, leaving it comparatively unobstructed at the surface of the deep and central parts of the ocean; and that therefore the unobstructed action of vis-inertiæ at the surface of the deep and central parts of the ocean, being a greater force, must overwhelm, to a greater or lesser extent, the lesser forces near the shores and bottom of the ocean.

Therefore the action of vis-inertiæ must tend to circulate the water by a stream running through the deep and central parts of the ocean in the opposite direction to that of the earth's motion, and along the shores in the direction of the earth's motion.

But as regards the action of vis-inertiæ resulting from the axial rotation of the earth, not only is there this difference in the effective force acting in different parts of the ocean, proportioned to the relative freedom from friction; but also, besides this, the actual velocity of the motion is not the same in all parts of the ocean, but is greater at the equator, decreasing gradually towards the poles ; and is greater at the surface, decreasing gradually towards the bottom of the ocean : and therefore, the actual action of vis-inertiæ is greater in equatorial than in polar regions, and greater in the upper than the lower strata of water, in proportion with the difference in the velocity of the motion of axial rotation in different latitudes, and at different depths of the ocean. And thus, therefore, notwithstanding that the velocity of the orbital motion of the earth, as also probably that of the motion of the solar system, is far greater than the velocity of the motion of axial rotation at any part of the earth's surface, by the latter motion a far greater amount of force effective in causing ocean currents may—indeed almost obviously must—be brought into play than can be brought into play by the orbital motion of the earth, or by any

simply onward motion of the earth through space. And therefore, in consequence of the difference in the velocity of rotation in different latitudes and at different depths of the ocean, the current-creating action of vis-inertiæ brought into play by the axial rotation of the earth is the great paramount force; and that which is brought into play by the orbital motion of the earth—as also that brought into play by the motion by which the earth is carried along through space with the solar system—simply causes deviations or variations from that which would be the course of the currents of the ocean if under the sole influence of the axial rotation of the earth.

We have seen that the westward pressure resulting from the axial rotation of the earth is fixed and unchanging in its action. But as regards any influence which may result from the orbital motion of the earth, such influence will obviously be not only itself a variable influence, acting at one season of the year with greater force than at another season; that is, acting with its greatest force in December, when the speed of the earth in its orbit is fastest, and with its least force in June, when that speed is slowest; all intermediate gradations of speed intervening: but also, it will be constantly changing its direction on any given point of the earth's surface, for at one season of the year the northern hemisphere, and at another season the southern, is inclined in the

direction in which the earth moves in its orbit ; and also, on the side of the earth turned from the sun the motion of axial rotation is in the same direction as that in which the earth is moving in its orbit, and on the opposite side of the earth in the reverse direction ; so that in March at midday this force acts about ENE.-wards, and at midnight about WNW.-wards ; whereas in September, at midday it acts ESE.-wards, and at midnight WSW.-wards ; all intermediate degrees of variation lying evenly between the extremes of daily and annual variation respectively. Thus, this force always acts eastwards in the daytime, and westwards at night, and always northwards in March and southwards in September ; oscillating continually backwards and forwards between the extremes of daily and annual variation respectively. The annual variation is confined within about four points of the compass ; that is, between $23\frac{1}{2}°$ north and $23\frac{1}{2}°$ south, and the daily variation extends over about fourteen points of the compass ; that is, from $66\frac{1}{2}°$ east to $66\frac{1}{2}°$ west, the greatest combined variation being from any one point to the opposite point of the compass, that is, the sixteen points.

In the annual variation this force turns more and more northwards from the 23rd of September to the 20th of March, and then from the 20th of March to the 23rd of September it turns more and more southwards. And in the daily variation the change

from an eastward to a westward direction occurs at 6 P.M., and that from a westward to an eastward direction at 6 A.M.

PART II.

EFFECTS OF THE MOTION OF THE SOLAR SYSTEM.

As regards the motion of the Solar System through space, of which a series of astronomical observations, originated by Sir William Herschel, has given us a partial knowledge; although, reasoning from analogy, any influence resulting from that motion will probably be among the forces which are subject to cyclical changes, yet, considering the enormous periods embraced in those cycles, the action of such forces may, as far as our present purposes are concerned, be regarded as fixed and constant at all points of the surface of the earth.

We have not, however, in this case, a knowledge of the motion from which to deduce effects, but the motion itself must be demonstrated by induction from its effects, if, reasoning from analogy, the existence of effects consistent only with some as yet unknown motion be demonstrated. And also it must be observed that any motion which may thus be demonstrated by the action of vis-inertiæ does not necessarily indicate simply a motion of the Solar System; for, as far as the evidence deducible from

the action of vis-inertiæ is concerned, the motion demonstrated might be the average result of a complication of various motions in different directions. It is obvious that since we have no definite *à priori* knowledge of such motion, we cannot do more than point out what the different possible effects of that motion might be; and if, after determining the effects of the rotation of the earth on its axis, and its motion in its orbit round the sun, we find in fact such deviations from the effects which those motions should cause as are in accordance with any one of the presumable motions of the Solar System through space, we shall then, from those effects, obtain a knowledge of the motion which causes them. And, in investigating the action of vis-inertiæ, it is not necessary to decide whether the motion demonstrated be a simple motion of the Solar System, or the average of a combination of various motions of which that system may partake.

If the course of this as yet unknown motion of the earth through space be in the plane of the ecliptic, it will then at one period of the year be in conjunction with the orbital motion of the earth, and at the opposite period of the year in opposition to that motion; gradually changing in the course of each year from complete conjunction to complete opposition, and again from opposition to conjunction. So that, apart from a knowledge of such motion, effects of vis-inertiæ observed in the ocean at any

one period of the year would appear inconsistent with effects observed at any other period of the year. If, on the other hand, the course of this unknown motion be in the line of the poles—then, if in the direction of the north pole, the action of vis-inertiæ would appear southwards at the surface of the deep and central parts of the ocean, and northwards along the shores; and if in the direction of the south pole, then its action would appear northwards at the surface of the deep and central parts of the ocean, and southwards along the shores.[1] And the action of vis-inertiæ will deviate more or less from the courses here described, according as the line of motion may deviate more or less from the line of the poles, or from the plane of the ecliptic.

[1] It is evident that by the action here explained a considerable amount of warm surface water might be transferred across the equator, counterbalanced by a flow of cold water in the under strata. Mr. Croll points out that if oceanic circulation were caused by differences of temperature it would tend to equalise the temperature of the opposite hemispheres, whereas if caused by the winds it would tend to increase any existing difference. And to this latter action he attributes alternate glacial epochs in the northern and southern hemispheres. As a circulation caused by vis-inertiæ might have that same effect, the suggested glacial epochs are not a valid argument in favour of the circulation being caused by the winds rather than by vis-inertiæ. This subject is further discussed in Chapter IV. of *The New Principles of Natural Philosophy*.

BOOK III.

ON THE ABSTRACT NATURE OF THE FORCE WHOSE CURRENT-CREATING ACTION IS DESCRIBED IN BOOK II.

VIS-INERTIÆ AND GRAVITATION.

CHAPTER IV.

GRAVITATION AND VIS-INERTIÆ ARE CONVERTIBLE TERMS AS FAR AS THE MOVEMENTS OF THE OCEAN ARE CONCERNED.

Let us now proceed to consider what the forces whose action we have described are in their abstract nature, and what relation they bear to the forces which cause the tides.

According to Kepler's first law of gravitation, enforced by Newton's demonstrations, the force of attraction proceeding from any body in space decreases in proportion as the square of the distance from which it acts increases; and if this be so, then, since the superficies of spheres increase in proportion as the squares of their radii increase, therefore, the force of attraction proceeding from any centre of gravitation must be exactly equal in the superficies of all spheres described from that centre of gravitation; and, therefore, though the relative force of that attraction, as regards other forces of attraction, must decrease with an increase of distance from the centre from which it proceeds, and a decrease of distance from other centres of attraction, and the individuality of its effects be overwhelmed by being rendered

comparatively infinitesimal in comparison with the greater force proceeding from other centres of attraction; it must nevertheless, of necessity, be a power acting throughout the universe, modifying more or less the effects of other forces of gravitation.

If this be not so, then the law of gravitation above mentioned is not true; for that law is an effect necessarily resulting from this as a cause. They are inseparable as cause and effect. It is the fact of gravitation being of the nature described which necessitates that the force of attraction proceeding from any power of gravitation must be inversely as the square of the distance from which it acts. And since this law could no more exist without gravitation being of the nature above described than gravitation could be of that nature without causing this law, it must be admitted that any given particles of the ocean are acted upon by forces of attraction proceeding from every power of gravitation in the universe.

Let us suppose those particles to be at any given time or place in the position in which the joint action of all powers of gravitation tends to hold them.

The particles in question are held by the earth's gravitation, as well as by universal gravitation; and therefore, when the earth moves it tends to draw those particles with it: but, since those particles are in the position in which universal gravitation tends to hold them, the action of the earth is, therefore,

in the opposite direction to that of the combined action of all other forces of gravitation. Thus, as the earth moves, tending to carry the particles in question with it, the action of the foreign force of gravitation necessarily tends to draw the particles in exactly the opposite direction to that in which the motion of the earth tends to carry them.

This latter is precisely the action of vis-inertiæ which we have described in the preceding Book; for those particles of the fluid on the surface of the deep and central parts of the ocean, being the least closely held to the surface of the earth, are most free to move in the direction in which the foreign force of gravitation tends to draw them; and those particles which, in consequence of their position, are more closely held to the earth's surface, and therefore offer more resistance to the action of the foreign force of gravitation, being under the dominion of the earth's power of gravitation, are by that power drawn into the positions vacated by those set in motion (in relation to the surface of the earth) by the foreign force of gravitation: and thus, as long as the motion which causes this opposing action of gravitation lasts, a constant circulation is effected. The opposing forces are—the earth's power of gravitation acting in one direction, and the combined action of all other powers of gravitation acting in the opposite direction.

Thus, the currents through the deep and central

parts of the ocean are caused by the action of the foreign force of gravitation, just as the counter-currents are caused by the earth's gravitation. The ocean, as a whole, must maintain its position in relation to the conflicting forces. And if, on the one hand, it may be said that the vis-inertiæ of the ocean, opposing the earth's tendency to carry it from its position, causes a current in one direction, and that the earth's gravitation draws counter-currents in the opposite direction; so also may it, with equal propriety, be said that the vis-inertiæ of the ocean opposes the action of the foreign force of gravitation, and, as the attraction of the latter tends to draw it from its position, and draws a current through those parts of the ocean most free to follow its attraction, the vis-inertiæ of the ocean maintains its position as a whole by means of counter-currents through those parts of the ocean which are least free to follow the attraction of the foreign force of gravitation. That which is the vis-inertiæ current, in relation to the earth's gravitation, is the attraction current in relation to the foreign force of gravitation; and those which are attraction currents in relation to the earth's gravitation are vis-inertiæ currents in relation to the foreign force of gravitation.

Thus the vis-inertiæ which draws the currents westwards in the equatorial regions is, in fact, attraction proceeding from the joint action of all foreign powers of gravitation; and the earth's power of

gravitation maintains the equilibrium of the ocean as a whole, by drawing an equal volume of water eastwards through the temperate zones: but, in fact, this latter movement, when considered in relation to the joint action of all foreign powers of gravitation, is just as truly a movement resulting from the vis-inertiæ of the ocean.

Vis-inertiæ and gravitation are, therefore, as far as the arguments hitherto adduced are concerned, convertible terms. Any effect termed an action of vis-inertiæ in relation to any given power of gravitation, is, in fact, the direct result of some other power of gravitation; and, inversely, any effect caused directly by any given power of gravitation is an action of vis-inertiæ in relation to some other power of gravitation.

The action of vis-inertiæ in the ocean and atmosphere can, therefore, with no more reason be denied than the action of gravitation towards foreign bodies. To study the movements resulting from the action of gravitation, or to study those resulting from the action of vis-inertiæ, are therefore simply different modes of studying the same phenomena. A movement of the waters of the ocean caused by the direct action of the sun's power of gravitation, tending to draw the ocean towards it, is, therefore, an action of vis-inertiæ in relation to the joint action of all other powers of gravitation: and the counter-action of vis-inertiæ, by which the ocean maintains its position in

relation to the conflicting forces, is just as certainly the direct action of those other powers of gravitation, tending to draw the ocean towards the position in which the combined action of their gravitation tends to place it.

Therefore, as, when the earth's gravitation is considered in opposition to all other powers of gravitation, the water drawn westwards through the equatorial regions by the latter is replaced by an equal volume simultaneously drawn eastwards, through the temperate zones, by the former power, so also, when the sun's gravitation draws a volume of water to the side of the earth turned towards the sun, the joint action of all other forces of gravitation draws an equal volume of water in the opposite direction, thus preserving the equilibrium of the ocean in relation to the conflicting forces.

In the consideration of the action of gravitation in causing the tides of the ocean, we may, therefore, consider the action of the sun and of the moon, each singly ; and that of all the other powers of gravitation jointly, under the title of *astral gravitation*, which is sufficiently appropriate, though the gravitation of the planets is included in it.

This force of astral gravitation may be defined as the combined action of the gravitation of the universe, excepting the force whose action it opposes. And vis-inertiæ is universal gravitation.

Let us now reconsider the nature of the forces

brought into play in the ocean and atmosphere by the motions of the earth.

As regards the earth's onward motion through space, we have shown that, in consequence of the action of friction along the shores and bottom of the ocean, vis-inertiæ causes a current along the surface of the deep and central parts of the ocean, where it is comparatively free from the opposing action of the force termed friction, in the ordinary acceptation of the term ; whilst counter-currents return inshore to the source of action. In this case the vis-inertiæ, which drives a current through the surface of the deep and central parts of the ocean in the opposite direction to that of the motion of the earth, is astral gravitation drawing those particles which, in consequence of their position in the ocean, are most free to follow the influence of its attraction, towards the position which its power of gravitation tends to give them. And the friction which opposes the force of astral gravitation along the shores and bottom of the ocean is the earth's gravitation, which, in consequence of the particles in those parts of the ocean being more under its dominion than those at the surface of the deep and central parts of the ocean, draws them into the position which it tends to give, and consequently carries them to those positions in relation to the surface of the earth which the particles most under the dominion of astral gravitation tend to vacate.

And, as regards the earth's axial rotation eastwards, we have shown that, in consequence of the greater velocity of rotation in equatorial regions, vis-inertiæ causes a current westwards in those regions, counter-currents running eastwards through the zones of lesser force in higher latitudes north and south. In this case, the vis-inertiæ acting in equatorial regions with greater force than in higher latitudes—in proportion with the greater velocity of the motion of rotation in those regions compared with that in higher latitudes—is the force of astral gravitation, which holds all particles equally to the position which it tends to give them ; but as the surface of the earth in the equatorial regions moves more rapidly than in higher latitudes, the particles in those regions have a great relative tendency in the opposite direction to that of the surface on which they rest ; because the surface runs with greater velocity from under the particles as they move towards the position which astral gravitation tends to give them. And over those parts of the surface of the earth where the action of astral gravitation is less, the particles, being relatively more under the dominion of the earth's gravitation, are drawn into the positions in relation to the surface of the earth which the particles most under the dominion of astral gravitation tend to vacate. Thus, as astral gravitation gives the water a relative motion in the opposite direction to that of the surface of the earth in the equatorial

regions, the earth's gravitation causes an equal volume to outrun the surface in higher latitudes, and thus the equilibrium of the ocean, as a whole, is maintained in the position in which universal gravitation tends to hold it.[1]

Thus, then, the whole system of oceanic circulation which we have shown to result from the action of vis-inertiæ—in consequence of the greater force brought into play in those parts of the ocean which are moved with greatest velocity overwhelming the lesser forces in other parts of the ocean, and in consequence of the force acting along the surface of the deep and central parts of the ocean overwhelming that acting along the shores—is just as truly the effect of the opposing action of astral and terrestrial gravitation, in consequence of the earth in its motion tending to carry the particles of the ocean from the positions in which universal gravitation tends to hold them.

[1] See also Chapter XXI., Proposition XXVII.

CHAPTER V.

THAT MATTER, BY VIRTUE OF AN INHERENT FORCE OF INERTION, ENDEAVOURS CONSTANTLY TO BRING ITSELF TO A STATE OF REST.

We have seen that, as far as their action in the ocean is concerned, vis-inertiæ and gravitation are convertible terms, according as a tendency to move to or from any given power of gravitation is referred to. It must not, however, be assumed from this that they are really in their abstract nature identical.

Newton defines vis-inertiæ as 'an innate force of matter, or power of resisting, by which every body, as much as in it lies, endeavours to persevere in its present state, whether it be of rest, or of moving uniformly forwards in a right line.'[1]

Now, that any bodies have an innate tendency to move uniformly forwards in a right line is mere assumption. And this has been assumed to be so because it was found that the sun's gravitation is constantly tending to draw the planets towards it; but as they do not approach the sun, it is clear that an equal force tends to carry them in the opposite

[1] *The Principia,* Book I., Definition III.

direction ; and this force, acting in opposition to solar gravitation, is assumed to be an innate tendency in the planets to move in straight lines, from which they are constantly deflected by the gravitation of the sun. This is mere assumption. It is not based on any known phenomena.[1]

It is said that in the simple case of a ball, thrown in the air or rolled on the ground, being set in motion, its vis-inertiæ tends to keep it in motion until it is stopped by the resistance of the air or the ground against which it runs. This is an error. It is not the vis-inertiæ of the ball which tends to keep it in motion. It is vis-inertiæ, and vis-inertiæ only, which stops, and must in time stop the course of that ball. Vis-inertiæ resists the motion of the ball from first to last. And it is because the force which set the ball in motion is not continuously acting, and because vis-inertiæ is continuously acting, tending to bring it to rest, that, no matter what the original velocity of the ball may be, its motion must at length be spent.

If the force which set a body in motion continue to act constantly upon it, the motion will be continued ; but if the motive force be removed, then vis-inertiæ, so far from tending to keep the body moving onwards in the motion communicated to it, must and

[1] The origin of this 'assumption' is more fully explained in Chapters XII., XVI., and IX. of *The New Principles of Natural Philosophy*.

will, sooner or later, according to circumstances, bring the body to a state of rest.

In the case of the ball just mentioned, the ball is taken from a state of rest ; a certain amount of force is requisite to take it from that state of rest, and that force is spent to overcome the vis-inertiæ of the ball ; still more force is requisite to hurl the ball into the air or along the ground. Here it may be said that, but for the friction of the air or ground, the ball would move continuously. This is an error. But even supposing it were only this friction (unassisted at all by the vis-inertiæ of the ball) which stops its motion, even then, since this friction is the communication of motion to surrounding particles whose vis-inertiæ resists the motion, it is the vis-inertiæ of matter which brings the ball to rest.

Let us, however, consider this case on its merits, apart from any previous arguments. The ball is thrown through the air. And the reason why the air tends to resist and check the motion of the ball is because the ball has to displace particles of the air in its passage ; and as motion from the ball is communicated to those particles, less in proportion remains in the ball. This is the same if the ball be rolled along the ground. The particles it strikes or touches, it tends, more or less, to move ; but the vis-inertiæ of those particles tends to keep them at rest, and therefore resists the effort of the ball to move them ; and thus the ball and the particles

of air or earth set in motion by the ball are at length brought to a state of rest by the vis-inertiæ of matter.

Now there is certainly no more reason for supposing the vis-inertiæ which brings the whole to a state of rest to reside in the particles of air and earth set in motion by the ball than in the ball itself set in motion by the hand. In fact, a certain amount of force is exerted to overcome the vis-inertiæ of matter, and an amount of motion in the ball and particles of air and earth which it sets in motion is caused in proportion to the motive force exerted; but, as the motive force is not continuously exerted, it must at length be exhausted, and the bodies set in motion be brought to a state of rest by the vis-inertiæ of matter.

It thus appears that if in any body whatsoever there be not some motive force acting continuously to keep it in motion, its own inherent property of vis-inertiæ must (even if no other cause arise), in the course of time, bring it to a state of rest.

Let us, however, proceed to consider on what grounds and by what arguments the motion of the earth round the sun has been asserted to be maintained by an innate property of vis-inertiæ, in consequence of which it tends to move uniformly forwards in a straight line. The force which keeps it in motion is said to be its innate property of vis-inertiæ; and the force which resists that of solar attraction, and thus keeps it at its mean distance

from the sun, is said to be the tendency of its vis-inertiæ to carry it uniformly forwards in a straight line.[1] The argument, as given by Newton in *The System of the World*, is as follows :—

[1] The first law of motion was invented after the discovery of the motion of the earth ; and was invented for the express purpose of explaining the earth's continuous motion.

No proof of that law can be given by physical phenomena about the earth.

Newton accepted it as a necessity for the purpose of explaining not only the continuous motion of the earth, but also its resistance to the centripetal force.

This latter was the purpose which made the law most immediately requisite to him. *The New Principles of Natural Philosophy*, p. 235.

Kepler first asserted the onward motion of the earth to be due to an axial rotation of the sun. But he then knew nothing of the laws even of the direct action of gravitation, and had not the slightest idea of the revolving action of gravitation exerted by the sun.

When Newton discovered the laws of gravitation, Kepler's idea was abandoned by every philosopher, as being incompatible with the laws of gravitation as far as they were then understood.

Newton himself says, regarding this point : 'Though gravity might give the planets a motion of descent towards the sun, either directly or with some little obliquity, yet the transverse motion by which they revolve in their several orbs, required the Divine Arm to impress them according to the tangents of their orbs.'[1]

And elsewhere he says : 'I do not know any power in Nature which would cause this transverse motion without the Divine Arm.'[2]

It was for the purpose of explaining this ceaseless motion of the earth without loss of velocity, that the idea was first conceived of matter having, when once in motion, an inherent tendency to continue perpetually in motion. *Idem*, p. 309.

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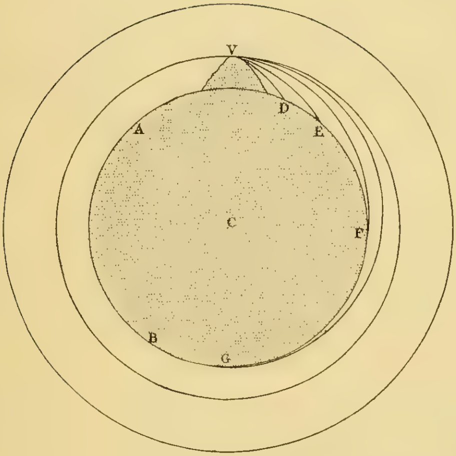
[1] Letter to Dr. Bentley, dated Cambridge, February 11, 1693.

[2] Letter dated January 17, 1693.



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'Let A F B (Plate XII.) represent the surface of the earth, C its centre, V D, V E, V F, the curve lines which a body would describe, if projected in a horizontal direction from the top of a high mountain successively with more and more velocity; and, because the celestial motions are scarcely retarded by the little or no resistance of the spaces in which they are performed, to keep up the parity of cases, let us suppose either that there is no air about the earth, or at least that it is endowed with little or no power of resisting: and for the same reason that the body projected with a less velocity describes the lesser arc V D, and with a greater velocity the greater arc V E, and, augmenting the velocity, it goes farther and farther to F and G; if the velocity was still more and more augmented, it would reach at last quite beyond the circumference of the earth, and return to the mountain from which it was projected.

The body is supposed to be projected with a horizontal force from V sufficient to carry it as far as D; then with a force sufficiently increased to carry it as far as E; then as far as F, and so on to G. Now, even admitting that each increase in the projecting force will carry the body still farther round the earth

Dr. Playfair tells us that but for the discovery of the motion of the earth, that law might have remained for ever unknown.[1]

I have shown that in the heavens that law is no longer required for the purpose for which it was invented. *Idem*, p. 245.

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[1] *Encyclopædia Britannica*, 8th Edition. Fourth Dissertation.

(supposing it to be free from the action of foreign forces of gravitation), and that it may be so increased as to carry the body quite round the earth, or an indefinite number of times round the earth, even then, that the body can twice return exactly to the point V, from which it started, or that it must not necessarily, sooner or later, in the course of time come to the surface of the earth just as certainly as that projected from V to D,—is not shown. And, in fact, it is certain that no increase in the amount of the projecting force can prevent the body from being gradually more and more deflected from the horizontal line, until it at length be brought to the surface of the earth. For the force with which the body is projected in the horizontal line is supposed to resist the force with which the earth draws the body towards its surface; but in resisting this tendency of the earth to draw the body towards it, a greater or lesser amount of force is necessarily spent. And as the force with which the earth draws the body towards it is continuous, which the projecting force is not, this latter must at length be spent by the constant resistance of the former; and the body, therefore, must at length be brought to rest on the surface of the earth, just as certainly, and for the same reasons, as in the case of the ball rolled along the ground. In both cases a certain amount of force is expended to set bodies in motion; and as the force is not continuous in its action, it is at length spent by the constant resistance

of the vis-inertiæ of matter. The force of friction which retards and at length stops the course of the ball rolled along the ground is (as we have before shown) exactly of the same nature as the force which resists that by which the body is supposed to be projected from v. The latter is the force of attraction caused by gravitation drawing towards the earth, and the former is the force of friction, in the ordinary acceptation of the term: but both these forces we have shown to be, in fact, simply efforts of vis-inertiæ constantly tending to bring matter to a state of rest. It is then evident that in the case of the ball thrown in the air, or rolled along the ground, as in the case of the moon revolving round the earth, there is no intrinsic difference in the nature of the force which tends to bring them to a state of rest on the surface of the earth.[1]

[1] The 'Laws of Motion' are more fully discussed in *The New Principles of Natural Philosophy*, especially in Chapters IX., XII., and XVI.; and partially in the Challenge-Lectures forming Chapters VI. and VII. of that work.

CHAPTER VI.

THAT THE MOON'S ORBITAL MOTION IS CAUSED BY THE EARTH'S ROTATION, AND ITS APPARENT LAGGING MOTION BY ASTRAL GRAVITATION.

We have already observed that the idea of any body having an innate tendency to move uniformly forwards in a straight line is mere assumption. No such innate tendency can, in the present state of knowledge, be demonstrated to exist in any known phenomena. And we have shown that if any body really has a tendency to move uniformly in a straight line, it certainly is not in consequence of an innate property of vis-inertiæ, because we have shown that its innate property of vis-inertiæ constantly tends to bring it to a state of rest: and therefore, if this tendency to move uniformly in a straight line exist, it must be in consequence of some force acting continuously with sufficient power to overcome the vis-inertiæ of the body set in motion.

The cause of the moon's motion is a question which has not hitherto been solved; and we have shown that the idea of the moon or any of the planets having a tendency to continue to move uniformly forwards in a straight line in consequence of an innate

property of vis-inertiæ is erroneous : and, therefore—comparing the motion of the moon in its orbit to that of the stone swung round in a sling, and tending constantly to fly off at a tangent from its course—it is evident that an innate property of vis-inertiæ, tending to carry the moon onwards in a straight line, is not the force which resists the earth's gravitation drawing towards the earth.

Now, since the earth's attraction tends to draw the moon to the earth, and the action of vis-inertiæ tends to bring the moon to a state of rest, just as in the case of a stone thrown in the air or rolled along the ground ; and as we have shown that the idea of any body having an innate tendency to move uniformly forwards in a straight line is a mere assumption : let us consider whether the fact of the moon not being drawn to the surface of the earth, and the fact of its moving continuously onwards in its orbit, cannot be explained without assuming the existence of any laws or forces whose action cannot be illustrated by analogy with known phenomena. The stone thrown in the air is drawn to the ground by the earth's attraction, whereas the moon is not. But then, as the moon is farther removed from the action of the earth's gravitation, and is therefore relatively more under the dominion of some other force of gravitation, it may, in the absence of any other reasonable cause being assigned, be inferred that the moon is held in equilibrium between the attraction of the

earth's gravitation and that of other forces of gravitation; so that, as the earth's attraction tends to draw the moon to the earth, those other forces tend equally to draw it in the opposite direction. Then the stone is drawn to the earth, but the moon is not, because the stone is within the sphere in which the force of attraction drawing towards the earth is greater than that drawing towards the position which any other force of gravitation tends to give it; whereas the moon is just so far removed from the earth as to be held in equilibrium between a tendency to the position which the sole action of the earth's gravitation would give it if unopposed by other forces, and a tendency to the position which, if the earth's force of gravitation were withdrawn, the combined action of all other forces of gravitation would give it.

This, however, accounts only for the moon withstanding the attraction towards the earth, whereas the theory which assumes an innate tendency to move uniformly forwards in a straight line accounts also for the moon's onward motion in its orbit. A cause for the onward motion of the moon, according with the action of well-known laws, is, however, indicated by the tides: for the moon tends to raise a mass of water, or tide, on the earth's surface beneath it; and, as the earth's surface rotates eastwards it tends to carry that mass of water or tide with it; and therefore, as the moon tends to hold the tide beneath it, the rotation of the earth eastwards must

just as certainly tend to carry the moon eastwards as to carry the tide eastwards.

The earth's gravitation, then, is constantly tending to draw the moon to the earth, and to carry the moon eastwards with the earth's axial rotation. But the moon is not drawn to the earth; and, as regards the earth's axial rotation, the moon is constantly lagging behind, or falling westwards.

The force by virtue of which the moon resists the motions which the earth's attraction tends to give it obviously accords with that which we have defined as its innate property of vis-inertiæ, by virtue of which it tends to maintain itself in a state of rest. And this vis-inertiæ we have shown to be universal gravitation.

The earth's gravitation tends to draw the moon to the earth, and the moon's gravitation tends to draw the earth to the moon, but by opposing forces of astral gravitation they are held in equilibrium. By some force (with whose nature we are not here concerned) the earth is caused to rotate eastwards on its axis, and as it rotates, its gravitation tends to carry the moon eastwards with that same motion; but the moon's vis-inertiæ resists this motion in precisely the same manner as that in which we have described the current-creating action of vis-inertiæ in the ocean, for the forces in play are precisely the same as those acting on any given particles of water. The earth tends to draw the moon to the position which the

earth's gravitation tends to give it; but the moon is already held in equilibrium by universal gravitation, and therefore, as the earth tends to draw it in any direction from that position, astral gravitation, or the combined action of all other forces of gravitation, tends to draw it in the opposite direction.[1]

[1] See *The New Principles of Natural Philosophy*, Chapter III.

CHAPTER VII.

THAT THE CURRENT-CREATING ACTION OF VIS-INERTIÆ, DESCRIBED IN BOOK II., IS CORROBORATED BY THE MOTIONS OF THE PLANETS.

THAT the earth's surface, in some manner, tends to carry the moon eastwards is indicated, as pointed out in the foregoing chapter, by the fact that the action of the moon's gravitation raises a tide which goes round with the moon, whilst the earth's surface rolls on eastwards under them. And, since the moon's gravitation drags westwards on the earth's surface (for it drags the tide westwards with it), that surface must, since the action of gravitation is reciprocal, tend to drag the moon eastwards. This reciprocal action of gravitation is inseparable from the existence of that force which, by Newton's demonstrations, may be said to have been removed from the domain of theory by being incontrovertibly established as a simple fact. And, therefore, the assertion that the earth's surface drags the moon eastwards is not only in accordance with Newton's laws of gravitation, but

it is, in fact, an inseparable corollary from them ; so that its refutation, of necessity, involves the denial of the existence of the force of gravitation. This being so, then any definitions or axioms invented to explain the onward motion of the moon and other heavenly bodies are, if at variance with the assertion that the earth's surface tends to drag the moon eastwards, of necessity false.

But if the moon is really carried round by the earth's surface rotating below it, then the far side of that surface, moving in the opposite direction, must tend to check it ; and, therefore, the velocity of its motion must depend on the amount by which the dragging power of the nearer exceeds that of the remoter part of the earth.

This argument, and with it the whole theory of the current-creating action of the earth's rotation, can be brought to a crucial test. For, if the motion of the moon in its orbit round the earth is caused by the earth's rotation, then it is to be presumed that the motions of the planets round the sun are caused by a rotation of the sun in the same direction as that in which the planets revolve ; and, therefore, according to the above argument, the relative velocities of the planets must show a dependence on the relative amounts by which the force of the gravitation of the nearer exceeds that of the remoter part of the sun in their respective orbits.

The exact relative amount of the revolving force in each orbit depends on the thickness of the surface whose gravitation causes the revolving action, and of this we have no definite knowledge. But, by taking the amount by which the force of the nearest exceeds that of the remotest part (or any other corresponding points in the opposite hemispheres) an approximation can be obtained, which is sufficiently accurate for our present purpose.[1]

The apparent motion of the spots upon the sun has long been supposed to indicate a motion of rotation in the direction above suggested. And the following tables show it to be a mere matter of fact that in the different orbits of the planets the fractions by which the force of the gravitation of the nearest part of the sun exceeds that of the remotest are such that their square roots represent the actual relative velocities with which the planets move in their orbits round the sun.

Taking the sun's diameter as 888,000 miles, the relative distances from the nearest and remotest parts of the sun respectively are approximately as in the first column of the following table, in which that diameter is taken as the unit of measurement :—

[1] See Table of Forces, Proposition XIX., Chapter XXI.

Relative distances from nearest and remotest parts of sun, in solar diameters			Inverse squares of distances give the proportion which in each orbit the gravitation of the remotest bears to that of the nearest part of the sun		Fraction of direct force which acts as a revolving force		Sq. Roots of foregoing fractions give relative velocities
Mercury	41	42	1,681	1,764	$\frac{83}{3445}$	= ·024092	·1552†
Venus .	77	78	5,929	6,084	$\frac{155}{12013}$	= ·012902	·1135†
Earth .	106	107	11,236	11,449	$\frac{213}{22685}$	= ·009315	·0965†
Mars .	164	165	26,896	27,225	$\frac{329}{54121}$	= ·006078	·0779†
Jupiter	556	557	309,136	310,249	$\frac{1113}{619385}$	= ·001796	·0423†
Saturn .	1,020	1,021	1,040,400	1,042,441	$\frac{2041}{2082841}$	= ·000979	·0312†
Uranus	2,051	2,052	4,206,601	4,210,704	$\frac{4103}{8417305}$	= ·000487	·0220†
Neptune	3,212	3,213	10,316,944	10,323,369	$\frac{6425}{20640313}$	= ·000311	·01763

The lengths of the orbits increase as the distances from the centre increase. And the relative lengths of the orbits, divided by the relative periods of orbital revolution, give the relative velocities of the orbital motions, as follows :—

Relative lengths of orbits		Relative periods of revolutions	Relative velocities of orbital motions
Mercury . . .	$41\frac{1}{2}$	88	·4715†
Venus . . .	$77\frac{1}{2}$	225	·3444†
Earth . . .	$106\frac{1}{2}$	365	·2917†
Mars . . .	$164\frac{1}{2}$	687	·2394†
Jupiter . . .	$556\frac{1}{2}$	4,333	·1284†
Saturn . . .	$1,020\frac{1}{2}$	10,759	·0948†
Uranus . . .	$2,051\frac{1}{2}$	30,687	·0668†
Neptune . . .	$3,212\frac{1}{2}$	60,127	·05342

† These decimals are all a fraction larger if extended. The least velocity is extended a figure farther to give greater precision when used as a divisor in the third table. The distances of the planets from the sun and the relative lengths of the orbits given above are based on the distances given in Mitchell's *Popular Astronomy*, discarding fractions of the solar diameter used as the unit of measurement, and the relative periods of revolution are, within half a day, the actual periods.

These actual velocities, deduced from the approximate measurements of the relative distances and periods, are the same as those in the theoretical table; for:

The relative velocities by the theoretical table are as under:		By actual measurement they are, according to the preceding table, as under:—	Taking Neptune's velocity as 10, both tables give, excepting fractions, the same velocity, as under:
Mercury	15,520	47,150	88
Venus	11,350	34,440	64
Earth	9,650	29,190	54
Mars	7,790	23,940	44
Jupiter	4,230	12,840	24
Saturn	3,120	9,480	17
Uranus	2,200	6,680	12
Neptune	1,763	5,342	10

The first of the foregoing tables shows that the fraction of the sun's direct force which acts as a revolving force is, approximately, inversely as the distance from the sun. And, as the total of the direct force is itself inversely as the square of the distance, the revolving force of the sun's gravitation is, therefore, inversely as the cube of the distance from the sun, approximately; and, this being so, it is then a mere matter of fact that the square roots of the revolving forces in the different orbits of the planets represent, approximately, the actually apparent velocities with which, if viewed from the sun, they would be seen to move, threading their way eastwards among the fixed stars. Or, in other words, the rapidity with which an orbital revolution is accomplished increases or decreases directly as the

G 2

square root of the revolving force of the sun's gravitation.

The revolving force of the sun's gravitation is, therefore, as the square of the angular velocity of the motion—that is, the velocity as measured on the surface of the sun which causes the motion.[1]

Now, since, according to the foregoing chapters, the earth is held in equilibrium between opposing forces of gravitation, therefore the retarding force of astral gravitation increases as the square of the velocity of the motion which it opposes (for the revolving force increases in that proportion).

The action of this retarding force of astral gravitation then makes the squares of the velocities of necessity inversely as the cubes of the relative distances; because, suppose the revolving force to be increased, then there is a corresponding increase in the opposing force of astral gravitation without any increase in the direct force of the sun's gravitation, and astral gravitation would then carry the earth back at a tangent to the orbit in which the revolving force tends to carry it, until, in consequence of the revolving force decreasing as the cube, and the direct force only as the square of the distance increased, the equilibrium between the force of astral gravitation drawing from the sun, and that of the direct force of the sun's gravitation, would be restored.[2]

[1] See also Proposition XVII., Chapter XXI.

[2] See Proposition XXV., Chapter XXI.

Now it must be observed that, in treating of the action of vis-inertiæ in causing currents in the ocean, we have been driven to the conclusion that the moon must be acted on by the same forces that impel any given drop of water through its circulation. That is to say, the revolving force of the earth's gravitation is constantly dragging them eastwards, whilst their own inherent force of inertion is constantly opposing that motion and causing them to lag westwards.

And then we have naturally inferred that the sun, by a motion of rotation, must tend to carry the planets round with it, just as the earth tends to carry along the water and the moon.

To test this we have calculated the relative force of the sun's revolving action in the orbits of the planets, considering that the nearest part of the surface tends to carry them in one direction, whilst the farthest part tends to carry them in the opposite direction, and we have found that the actual relative velocities with which the planets move round the sun bear a fixed ratio to the relative amounts by which the force of the gravitation of the nearest exceeds that of the remotest part of the sun in their respective orbits.

When a theory which explains the movements of the ocean and atmosphere—as shown in *Vis-inertiæ*, and farther on in this volume—is corroborated like this by the motions of the heavenly bodies, and wherever extended finds nothing in nature at

variance with it, of what avail is it to oppose it with ideas which, though asserted to be laws of motion, are merely theoretical, for they are not corroborated by phenomena observed in nature. The more clearly those so-called laws are shown to be at variance with the theory substantiated by natural phenomena throughout the visible universe, the more certain and complete must be their destruction.

According to the above-mentioned laws the moon's orbital motion is maintained by its inherent tendency to keep itself in motion—that motion having been communicated to it at some unknown period, by some unknown cause: and then the force which resists the earth's gravitation is said to be the tendency of that motion to carry it onwards at a tangent from its orbit, like a stone from a sling. Whereas, according to the arguments in the foregoing Chapters of this Book, the earth's gravitation is the motive force which draws the moon onwards in its orbit, and the centripetal and centrifugal forces, which by their opposing action keep it at its mean distance from the earth, are—the former terrestrial and the latter astral gravitation. These centripetal and centrifugal forces are of a very different nature from those in the case of a stone swung round in a sling. Let us consider what the difference is.

As regards the centripetal force: the string holding the stone in its course has been compared to the earth's gravitation holding the moon in its course.

The string certainly holds the stone in its course as long as the motion lasts, but there the analogy ends. And as regards the centrifugal forces there is no analogy in the two cases, excepting the fact of both tending to carry the revolving body from the centre round which it revolves. In the case of the stone, the centrifugal force gives the stone a tendency to fly off at a tangent from the circle in which it is revolved, *in the direction of its motion.* But, as regards astral gravitation, considered as the centrifugal force which opposes the centripetal force of the earth's gravitation: if the moon were not acted on by the revolving force of the earth's gravitation, but only by the direct force, then astral gravitation would tend to carry the moon directly from the earth, not at a tangent to any part of its orbit: and when in motion, astral gravitation tends to carry the moon off at a tangent from its orbit certainly, but *in the opposite direction to that of its motion.* The centrifugal force endeavours to place the moon at C in the higher orbit, C D E, instead of at B; to which latter it is carried by the revolving force along its orbit from A.[1] (Fig. 19, p. 88.)

[1] The reader will observe that the theory of counter-attraction, or astral gravitation, need not be considered to supplant the Newtonian theory of centripetal and centrifugal forces, but rather to define the nature of the latter force; showing that it is similar to the former: both being gravitation caused by vis-inertiæ, which is just as much the primary cause of the centripetal as of the centrifugal force.

The effects are matters of observation, so that the point at

The force of universal gravitation in fact opposes the motion of the stone in the sling just in the same manner as that of astral gravitation opposes the motion of the moon; but there is this radical differ-

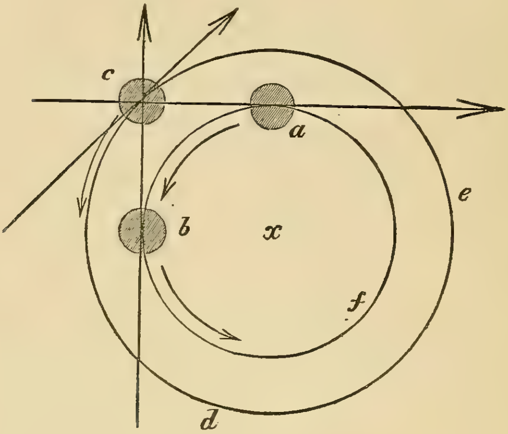


Fig. 19.

ence between the case of the stone revolved in the sling and that of the moon revolving round the earth.

issue is as to how those effects are caused; and I maintain that vis-inertiæ holds the planets in equilibrium, the centripetal force of the sun's gravitation being a part of the action of the planet's vis-inertiæ just as much as the centrifugal force. The error lies in the cause to which the tangental effort is attributed; and I have endeavoured to show that that effort is not caused by the vis-inertiæ of the planet tending to carry it onwards along the tangent, but by astral gravitation (a part of the action of vis-inertiæ) retarding it, and tending to draw it backwards farther and farther from the successive positions to which the revolving force carries it along its orbit.

Vis-inertiæ is the combined action of universal gravitation, which actually does keep the planet on the line of its orbit; opposing any tendency from, as much as towards, the sun.—*The Elements*, Preface, Vol. I. London, 1866.

In the former case it is *the motion* of the stone which tends to carry it out of the circle in which it is revolved: whereas in the case of the moon, as we have shown that the motion is caused by the earth's gravitation, it cannot tend to carry the moon onwards at a tangent from its orbit, nor indeed can it tend to carry it out of its orbit at all. The root of the difference is this: the force by which the stone is set in motion is an illustration of the direct action of the forces ordained to control matter; whereas, in the case of the moon, the motion is caused by gravitation, an attribute of vis-inertiæ—the mode, in fact, in which vis-inertiæ manifests its resistance to the motive force.

The motion of the moon in its orbit may rather be compared to that of a cork floating in a basin of water, in which, by rotating any object rapidly in the centre of the basin, the whole mass of water is caused to rotate, carrying the cork along with it. The motion of the moon and that of the cork are analogous, inasmuch as both are caused by gravitation, this gravitation being an effect resulting from the resistance which the vis-inertiæ of matter presents to the action of the force by which the object in the centre of the basin is made to rotate. This is so because, in consequence of its property of vis-inertiæ, the water in the basin tends to maintain itself in a state of rest; and therefore, resisting any force which may tend to set it in motion, it endeavours to maintain its position and that of its parts in

relation to each other. When, then, the object in the centre of the basin is made to rotate, those particles of water adjoining the rotating surface endeavour to maintain their position in relation to the part of the rotating surface against which they rested, and also in relation to those particles next beyond them ; and therefore draw towards the part of the surface caused by the action of the extraneous force to tend from them, and also towards those particles next beyond them, these latter towards those next them, and so on ; and thus all the particles, each endeavouring to maintain its connection with those next to it, draw or gravitate towards each other. Thus the gravitation of the particles one towards another draws the whole mass onwards in a motion of rotation, each endeavouring to maintain its position in relation to the particles set in motion by the action of the extraneous force : and therefore, as the object in the centre of the basin is made to rotate, the force of gravitation causes the cork to revolve in the same direction. This is analogous to the motion of the moon revolved eastwards in its orbit by the force of its gravitation towards the surface of the earth rotating eastwards. In the case of the moon, as in the case of the cork, the motion is caused directly by gravitation, which is the effort of vis-inertiæ to maintain matter in a state of rest :—it is the force exerted in the endeavour to resist the action of any forces which tend to cause a change of form or posi-

tion. These motions result from the efforts of the particles of matter to maintain the positions in relation to each other which the extraneous force disturbs; whereas the motion of the stone in the sling is caused directly by the extraneous force carrying the stone onwards in accordance with its laws, in spite of the resistance of vis-inertiæ. The stone is hurled through the air in direct opposition to the force of gravitation; and after it is released from the sling the motion communicated to it must, sooner or later, be spent by the continuous resistance of vis-inertiæ.

An increase of the velocity of rotation which revolves the cork and the water above mentioned will cause the particles of water and the cork to recede from the centre along tangents backwards from the successive points to which the revolving force endeavours to carry them in the circles of revolution (as shown by the diagram on page 88); because, as has been shown in the preceding chapter, the retarding force of astral gravitation increases as the square of the velocity of the motion which it resists; and it will therefore carry the revolving particles backwards from the centre of revolution until the disturbed equilibrium is readjusted in consequence of the revolving force decreasing as the cube of the distance from the centre increases.

As the water recedes along the tangents it exemplifies the overwhelming of lesser forces by greater.

For the revolving force increases towards the centre, and as any particle is carried onwards by it, the particle next outside it is carried relatively in exactly the opposite direction by the force of astral gravitation, the action of which is relatively greater, as regards the revolving force, on it than on the particle nearer the centre of rotation. Its motion backwards along the tangent results from the effort of vis-inertiæ to maintain the equilibrium destroyed by the particles nearer the centre of rotation being carried in the opposite direction.

The above argument is equally applicable to the moon; for, suppose the latter to be lying loosely on the surface of the earth, and let a motion of rotation be generated in the earth, and then, as that motion carries the surface on which the moon rests onwards, astral gravitation, whose action, compared with the revolving force, is relatively greater on the moon than on the surface below it, maintains the equilibrium of gravitation by carrying the moon in the opposite direction, which is backwards along the tangent to the surface on which it rested. And it will continue to recede along that tangent as long as the disturbed equilibrium is more readily restored by that motion than by the motion of the opposite side of the rotating surface, or of some other body in the same direction. At the distance thus determined it would revolve with the rotating surface, though constantly lagging backwards over it under the action

of astral gravitation. Thus the force of astral gravitation, opposing that of the earth's gravitation, is constantly endeavouring to draw the moon out of its orbit, and the earth's gravitation revolves it in the orbit in which it is held by those opposing forces.

The foregoing shows that it is an error to suppose the orbital motion of the moon to be analogous to that of a stone swung round in a sling. Because: it is the motion of the stone which tends to carry it out of its orbit; that motion tends to carry it onwards at a tangent to its orbit in the direction in which it is revolved; and the motion is caused by a force which moves the stone in spite of the resistance of vis-inertiæ. Whereas: it is the force which opposes the motion of the moon that tends to carry it out of its orbit; that force tends to draw it backwards in the opposite direction to that in which it is revolved; and the motion of the moon is caused by gravitation, which is the effort of vis-inertiæ to bring matter to a state of rest. For the motion of the moon is its effort or gravitation towards the nearest part of the surface of the earth which is constantly rolling from it. An increase of the velocity with which that surface moves would increase the distance to which the moon is drawn from it; because the force of astral gravitation which prevents the moon from keeping pace with the surface increases as the square of the velocity of its motion.

To make this clearer we may recapitulate:

As the ratio in which the force of astral gravitation increases or decreases is dependent on that of the revolving force; and as the latter is inversely as the cube of the distance, whereas the direct force is inversely as the square of the distance from the earth, therefore, however great the revolving force may be at the surface of the earth, the opposing force of astral gravitation which carries the moon backwards from the position to which the revolving force tends to carry it must at some certain distance become equal to the direct force of the earth's gravitation; and there the moon would be revolved in equilibrium between the force of astral gravitation tending to draw it out of its orbit from the earth and that of the earth's gravitation tending to draw it to the earth.

In the case of the stone, the motive force tends to carry it off at a tangent to the circle in which it is revolved in the direction of its motion, in spite of the resistance of vis-inertiæ, which tends to bring it to a state of rest: whereas the moon is held in equilibrium by vis-inertiæ, or universal gravitation, whilst the force of astral gravitation tends to carry it from the earth, and the earth's gravitation tends to draw it to the earth; and its motion is constantly restoring the equilibrium of gravitation towards it as fast as that equilibrium is disturbed by the action of the force which causes the earth to rotate.

The motion of the stone disturbs the equilibrium

of gravitation, whereas the motion of the moon maintains it.[1]

[1] Newton erred in assuming the centrifugal force which opposes the centripetal force of solar gravitation, and holds the planets at their mean distances from the sun, to result from an innate tendency to move uniformly forwards in a straight line : and he doubly erred in assuming this asserted tendency to move uniformly forwards in a straight line to result from innate vis inertiæ, by virtue of which any body once set in motion tends to continue that motion uniformly forwards in a straight line until other forces from without stop it. For, first, I have shown that vis-inertiæ opposes motion in everything, and that its own inherent property of vis-inertiæ must tend to bring a body to rest, under any circumstances whatever, just as much, and in the same manner, as the action of any force from without. And, secondly, I have shown that, as regards the motions of the planets in their orbits, the centrifugal force which opposes the centripetal force of the bodies which compose the solar system one towards another, and all towards their common centre of gravity, is the force of astral gravitation opposing that of solar gravitation ; so that, in their courses, they are borne smoothly along the lines of equilibrium lying between opposing forces of gravitation. This subject is more fully discussed in *The New Principles of Natural Philosophy.*

CHAPTER VIII.

THE MOTIVE FORCE.

The foregoing chapters of this Book have shown that vis-inertiæ is a really inherent property in matter, by virtue of which it endeavours to be just what it is and where it is ; and that gravitation is simply an effect of vis-inertiæ—this effect of vis-inertiæ being brought into existence in consequence of the action of some other force tending to cause a constant change of form and place.

They have also shown that this motive force acts from the central parts of the sun, causing the latter to rotate and to revolve the surrounding planets with it. And that a similar motive force acts from the central parts of the earth, causing it to rotate and to revolve the moon in the same direction.

Whatever be the source or abstract cause of the force which rotates the earth and the sun as above shown, the term *evanescence* may appropriately be applied to it in a limited sense, and even a comprehensive signification of the term may be shown to be not inappropriate. For the tendency of the sole action of gravitation would be to consolidate the universe into one motionless mass ; but if evanescence

be brought into play throughout it, then motion is necessitated; for evanescence implies a motion of the evanescing particles, and gravitation, tending to cause contraction, necessitates a motion of the remaining particles: and since contraction is a necessary consequence of evanescence, having effect wherever evanescence occurs, it must act towards every point from which evanescence acts, and thus divide the universe into separate masses; and the motion resulting from this contraction must be more or less circular, because the position of every particle is determined by gravitation, and every division of the universe must therefore preserve its relative position as regards the aggregate of the other divisions of the universe, which necessitates a motion of rotation in each division; and the particles rotating must all move harmoniously, because the force of attraction acting from all sides prevents the movement of any one particle unless there be an harmonious movement of some other particle or particles, so as to preserve the balance of gravitation.

Even under its most limited signification the force of evanescence, which vis-inertiæ is, by the act of gravitation, constantly opposing, comprehends the detailed action of the laws which control matter; and the evolution of life upon the earth is therefore the action of evanescence, which causes it to rotate. And if accepted in its widest sense, it is then to be inferred that matter has not always existed, and that

in the course of time it will cease to exist: presuming, of course, that it is only reasonable to suppose that something immaterial pre-existed from which it had its origin, and that when it has run its course and ceased to exist, something immaterial evolved from it will exist after it. We are, however, concerned only with the forces brought into play by the evanescence of matter, and not with the immaterialities which pre-existed, or into which it is in process of transmutation; and these forces, termed *evanescence*, tending to control matter in a constant series of evolutions through its existence, causing constant change of form and place, bring into play the force of gravitation in consequence of the action of vis-inertiæ, by virtue of which matter tends to preserve its existence, or hold itself together, and continue where and what it is.[1]

[1] See Chapter XIX. of *The New Principles of Natural Philosophy*, 'Is force inherent in matter? And is matter evanescent or indestructible?'

BOOK IV.

EFFECTS OF SOLAR AND LUNAR GRAVITATION.

THEORY OF THE TIDES.

CHAPTER IX.

NORMAL POSITIONS OF THE TIDES IN RELATION TO THE FORCES BY WHICH THEY ARE RAISED.

THE position which the ocean would have under the sole influence of terrestrial gravitation is modified by the gravitation of other bodies in space, which tend to draw the water to the parts of the surface of the earth turned towards them.

The sun, the moon, and the planets all tend, more or less, to draw the water to those parts of the earth's surface turned towards them. And by the earth's motions the parts of the surface of the earth turned towards the foreign bodies respectively are being constantly changed. The gravitation of those bodies constantly tends to hold the water in the position which they tend to give it, whilst the earth's gravitation as constantly tends to carry the water away from that position, together with the surface on which it rests.

Let us now suppose all other bodies of the Solar System to be so far removed from the earth that the individuality of their forces of gravitation on the earth may be lost in that of the remaining force—which is, in fact, that of the stars, or, as we have before termed it, astral gravitation.

Discarding in this manner the individual action of the sun and moon, we have seen that the ocean has a tendency to maintain the position from which the surface on which it rests tends to carry it: and that this tendency results from its property of vis-inertiæ, in the ordinary acceptation of the term; but we have also seen that the action of vis-inertiæ which resists motion towards the position which the earth's power of gravitation tends to give, is a power of gravitation drawing towards the position which the combined action of all powers of gravitation, excepting that of the earth, tends to give. To this force we have applied the term 'astral gravitation,' because we have ascertained that vis-inertiæ is really universal gravitation, which this force is not.

The oceanic circulation resulting from the conflicting action of these forces of terrestrial and astral gravitation we have described at length in Book II., in which we have shown that, as regards the onward motion of the earth, in those parts of the ocean least under the dominion of the earth's gravitation, a current is drawn through the ocean, by the attraction of astral gravitation, in the opposite direction to that of the motion of the surface of the earth; whilst in those parts of the ocean most under the dominion of the earth's power of gravitation counter-currents are drawn through the ocean, by the earth's gravitation, in the direction of the motion of the surface of the earth.

Fig. 1.

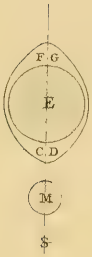


Fig. 4.

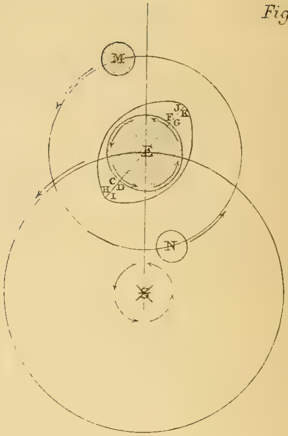


Fig. 2

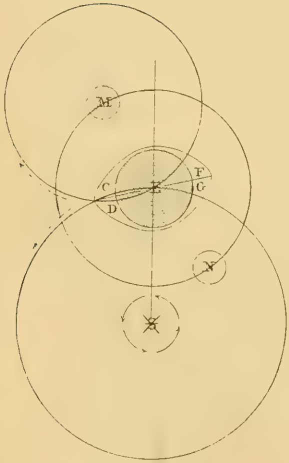
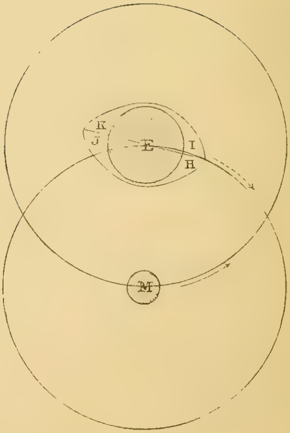


Fig. 3.



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And, as regards the axial rotation of the earth, as that rotation is eastwards, the earth's gravitation tends to carry the ocean eastwards with the surface on which it rests ; but astral gravitation, drawing in the opposite direction, tends to give it a relative motion westwards over the surface of the earth all round the earth. But as the stars draw the water westwards through the equatorial regions, where the force of their gravitation, compared with that of the earth, is relatively greater than in the temperate zones, the earth's gravitation draws an equal volume eastwards through the temperate zones, in which the force of its gravitation is relatively greater than in the equatorial regions :[1] and also as the stars draw the water upwards from the surface of the earth in the equatorial regions, the earth's gravitation draws an equal volume downwards to the surface of the earth in the temperate zones. From this opposing action of astral and terrestrial gravitation there results the elaborate system of oceanic circulation described in Book II. The circulation there described is quite independent of the individual action of the sun and moon, though the gravitation of those bodies is included in the force of gravitation whose combined action causes that system of circulation. The opposing forces of terrestrial and astral gravitation together represent universal gravitation or the action of vis-inertiæ.

We have, in Book III., shown that in the same

[1] See Chapter XXI., Proposition XXVII., Sect. 6.

manner as that in which astral gravitation opposes terrestrial gravitation it must also oppose the action of solar and lunar gravitation, causing a counter-movement for each movement caused by the latter forces. The movements and the counter-movements in each case equally result from the effort of vis-inertiæ to maintain the equilibrium of the ocean.

In the same manner as vis-inertiæ creates the movements and counter-movements which circulate the ocean, as described in Book II., in consequence of inequalities in the action of terrestrial and astral gravitation, it must also, as shown in Book III., create movements and counter-movements in consequence of inequalities in the action of solar or lunar and astral gravitation. The consideration of the action of vis-inertiæ thus leads us to a consideration of the effects of solar and lunar gravitation on the ocean, as forming a part of that action of vis-inertiæ.

Let us now consider the effect of the gravitation of the sun and moon in their actual positions.

For this purpose let S, in Plate XIII., represent the sun, E the earth, and M the moon. Then, first, as regards the solar tides: if the sun and earth be at rest, the sun's gravitation raises a tide (C D in Fig. 1) on that part of the earth immediately under the sun, and astral gravitation raises a tide (F G) on exactly the opposite side of the earth.

The sun, however, rotates eastwards on its axis,

and as it rotates its gravitation tends to carry the earth with it, the latter endeavouring to maintain its position in relation to the nearest part of the surface of the sun. But as the sun's gravitation endeavours to carry the earth eastwards, it endeavours to draw it from the position in which astral gravitation tends to hold it. And this latter force prevents the earth from maintaining its position in relation to the rotating surface of the sun. And though the earth is drawn onwards in its orbit by solar gravitation, it is, in consequence of the retarding action of astral gravitation, constantly falling westwards in relation to the surface of the sun.

As the attraction of solar gravitation draws the earth onwards in its orbit, it draws the solar tide (westwards in relation to the surface of the earth) to that part of the surface of the earth which is in advance in the earth's orbital motion. This is a meridian somewhat nearer that of the sun than the meridian of 6^h A.M. Let us, for the present arbitrarily, suppose this to be the meridian of $6\frac{1}{2}^h$ A.M. And astral gravitation—acting in exactly the opposite direction to that in which the sun's attraction tends to carry the earth—draws the counter-tide westwards, to the part of the earth opposite that to which the solar tide is drawn. This is a meridian more remote from the sun than the meridian of 6^h P.M., and doubly remote from that which is most behind in the central line of the earth's orbital motion. The positions of the solar tide C D,

and the solar counter-tide F G, would then be as shown in Fig. 2.

Then as regards the lunar tides : the action of the moon on the lunar tides is exactly the reverse of that just described as the action of the sun on the solar tides : for the earth is revolved in its orbit round the sun by the force of solar gravitation, which raises the solar tide ; whereas it is the earth's gravitation which revolves the moon in its orbit round the earth. But we may, for the sake of simplifying the question, just for the present, suppose the earth to be revolved round the moon in the opposite direction to that of the real motion of the moon round the earth.

Then, as the moon revolves eastwards round the earth, the relative positions of those bodies and the lunar tides are the same as if the earth be supposed to revolve westwards round the moon. Then, as in the case of the solar tide, the lunar tide, I H, in Fig. 3, is drawn to that part of the earth's surface which is in advance in this orbital motion, and the counter-tide, J K, is drawn by astral gravitation to exactly the opposite side of the earth.

In consequence of the smallness of the moon's orbit, the lunar tides are drawn more towards the moon's meridian than is the case with the solar tides in relation to the sun's meridian. Let us, for the sake of illustration, suppose this difference to be double that in the case of the solar tides. Then, as there is a difference of an hour in the relative distances of the

solar tide and the solar counter-tide from the sun's position (those tides corresponding with the meridian of $6\frac{1}{2}^h$ A.M. and $6\frac{1}{2}^h$ P.M.), there will be a difference of two hours in the relative distances of the lunar tides from the moon's position.

Therefore, though if the sun, moon and earth were at rest, then the tides raised by the sun and moon would be in conjunction at the same time as they; as the earth and moon are in motion, the tide raised by the sun's gravitation as it revolves the earth round the sun, and that raised by the moon's gravitation as the earth revolves the moon round it, will not be in conjunction when the sun and moon are in conjunction, because the position of the solar tide being $5\frac{1}{2}^h$ west of the sun's meridian, and that of the lunar tide being 5^h east of the moon's meridian (for the moon follows its tide), therefore the lunar tide can only be in conjunction with the solar tide when the moon is 5^h west of the meridian of $6\frac{1}{2}^h$ A.M.—that is, when the moon is on the meridian of $1\frac{1}{2}^h$ A.M. The moon reaches this latter meridian in rather less than two days after being in opposition to the sun. Therefore, about two days after the sun and moon being in opposition, the lunar and solar tides will be in conjunction (as at C D in Fig. 2), their counter-tides also being at the same time in conjunction on the opposite side of the earth (as at F G). But also when the moon is at the opposite point of its orbit (as at N), two days after conjunction with the sun,

the lunar tide will be in conjunction with the solar counter-tide, and the lunar counter-tide at the same time in conjunction with the solar tide. Thus about two days after conjunction, and also two days after opposition of the sun and moon, their tides (as a whole) are in conjunction, and not when the sun and moon are themselves in conjunction and opposition.

And then the combined action of the sun and moon endeavours to place the high spring tide on the meridian of $6\frac{1}{2}^h$ A.M.

Thus, as shown in Fig. 2, the tidal action of the moon acts in conjunction with that of the sun at the moment when the earth's course westwards round the moon is in conjunction with its course eastwards round the sun.

The solar and lunar tides are again in conjunction when the earth's course westwards round the moon is exactly in opposition to its course eastwards round the sun. But in the latter case the solar tide is not, as in the former case, in conjunction with the lunar tide, but with the lunar counter-tide; the lunar tide being at the same time in conjunction with the solar counter-tide.

From this it is obvious that the study of the tides would be simplified and rendered more accurate by dating the hour of the 'establishment' of ports from the time when the earth's course round the moon is in conjunction with, or opposition to, its course round

the sun, than by the present method of taking as the 'establishments' the hours at which the first high tide occurs at the various ports after the sun and moon being in conjunction or opposition.

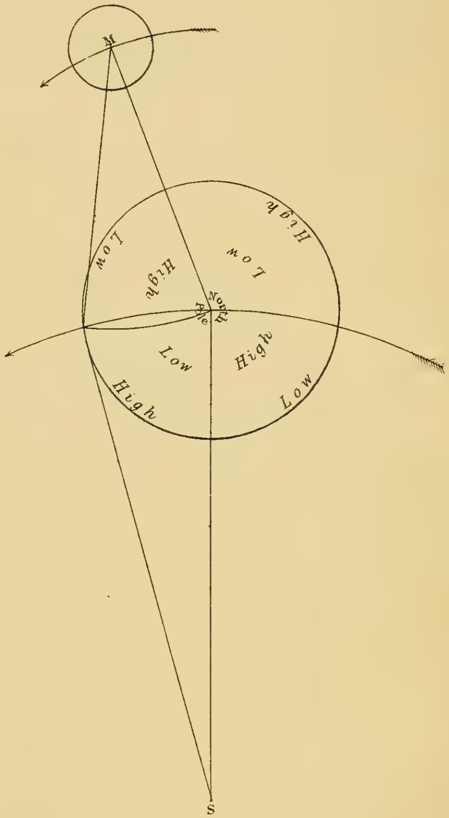
For the time when the earth's course round the moon is in conjunction with its course round the sun is the normal hour of the monthly conjunction of the lunar with the solar tide, and therefore the 'priming' and 'lagging' of the tides throughout the month may be calculated in a more simple and accurate manner by considering this as the commencement and close of the tidal months, and by reckoning the cycle of variations in the alternate 'priming' and 'lagging' of the tides through these intervals, instead of through the intervals between the times of new moon.

CHAPTER X.

MOVEMENTS OF THE TIDES IN RELATION TO THE SURFACE OF THE EARTH.

We have thus far determined the positions, in relation to the sun and moon respectively, in which those bodies tend to raise their tides, supposing the earth simply to be moved onwards in its orbit round the sun, or in an orbit round the moon. Let us now consider how these positions will be affected by the earth's axial rotation, and what course this rotation will give them over the surface of the earth.

In the position of the tides in Fig. 2, Plate XIII., the effect of the axial rotation of the earth has not been taken into consideration at all. We have seen that the solar and lunar tides are in conjunction when the relative positions of the sun and moon are such that the earth's motion eastwards round the sun, or westwards round the moon, are in the same line. And therefore, if the earth did not rotate on its axis, the solar and lunar tides at the time of conjunction would be on that part of the earth which is in advance in those motions, the two counter-tides being together on the opposite side, as in Fig. 2. But, as the earth rotates eastwards on its axis, it tends to carry the



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tides with it towards the position shown in Fig. 4. They constantly endeavour to get into the positions in which the lunar and solar forces respectively tend to place them ; but the surface of the earth, on which they rest, as it revolves eastwards, is as constantly endeavouring to carry the tides eastwards with it.

And therefore, whatever may be the normal velocity with which water would move through the ocean under the action of the luni-solar force towards the meridian on which that force tends to place the tide, it must be constantly rising towards that meridian from the east in the equatorial regions, and from the west in the higher latitudes in which the velocity with which the surface rotates eastwards is less than the normal velocity of the tide.

Thus, as shown in Plate XIV., the high spring tide would lie diagonally across the meridian of $6\frac{1}{2}^{h}$ A.M., so that in the temperate regions the surface of the earth would reach it in the early morning, and in the equatorial regions not until during the forenoon. And therefore, if an unbroken expanse of ocean covered the earth, the hours of high water at different places would increase as the distance from the equator decreased, for the tide would first touch the meridian in high latitudes, and then travel down it from the north and south to the equator, and then fall on the equator as it rose again along the meridian in higher latitudes.

Thus the luni-solar tide on the side of the earth

in advance in the orbital motion, and the counter-tide on the opposite side, would, whilst keeping their positions unchanged in respect to the forces by which they are raised, appear to have cyclonic movements, for they would (even if their course were due west) alternately rise and fall towards and from the equator along each meridian just as much as east and west along each parallel of latitude.

The tide, though travelling round the earth from east to west, would commence on any meridian in high latitudes in the form of an undulation rising from the west, and would then converge along the meridian towards the equatorial regions where the undulation would be from the east, so having the apparent motion of a cyclone on each side of the equator : for, as already shown, the tide is in a chronic state of trying to place itself on the meridian on which the luni-solar force tends to raise it ; but, as the earth's rotation as constantly prevents it from achieving this, it is for ever rising towards it from the west in high latitudes, and from the east along the equator, being upon it only in the intermediate latitude, in which its normal velocity is the same as that with which the latitude rotates.

Thus it is evident from the foregoing that, though the whole tide travels westwards, not only have the tidal undulations movements in opposite directions in the temperate and equatorial regions, but, besides this, recorded times of high water would show a

regular rise and fall along each meridian, as well as along the parallels of latitude.

It will be observed that the action here described harmonises with the views arrived at in Book III., through the arguments in that and the preceding Books, for though we have here shown that the tide is carried eastwards in the equatorial regions by the earth's rotation, it is just as true, according to the action of vis-inertiæ described in the foregoing Books, that, as in the equatorial regions the tides vibrate westwards, following the force which raises them, where its action is relatively greater than the earth's gravitation, at the same time, in the temperate zones, where the earth's gravitation is relatively greater than that of the foreign force, it causes an equal vibration eastwards, and so maintains the equilibrium of the ocean; and therefore, though in the ocean as it exists the tides cannot sweep round the earth with the regular cyclonic vibrations above described, their course will be determined by the action of vis-inertiæ —for the same counteracting forces are brought into play in each instance, preserving the equilibrium of the ocean. If the latter surrounded the earth as an unbroken expanse of water, then the tides would simply be excrescences upon the ocean, through which the circulation described in Book II. would run its course without being affected by them. And in the actual ocean, though the fragmentary tides will be sources of disturbance, as they are broken and de-

flected by the coast-lines, the undulations must nevertheless be under the dominion of the forces there described: according to which, as the luni-solar forces move westwards in relation to the surface of the earth, they carry the tides westwards with them in the equatorial regions, in which the force of their attraction is greatest; whilst, at the same time, the force of terrestrial gravitation maintains the equilibrium of the ocean on the surface of the earth by drawing an exactly equal mass of the tide eastwards through the temperate zones, in which the ocean is more under the dominion of the earth's gravitation, and less under the dominion of the forces which raise the luni-solar tides, than in the equatorial regions. And thus, therefore, the relative volume of water on every meridian, and on every parallel, can never vary.

The position of the ocean in relation to the surface of the earth is determined by universal gravitation or vis-inertiæ, and is constantly the same both in longitude and latitude. Though the luni-solar forces change their positions in relation to the surface of the earth, the volume of water on every meridian and on every parallel remains, nevertheless, constantly the same; because this is determined by the combined power of the gravitation of the universe, and cannot be affected by the individual action of any of the forces of gravitation within the universe. As the luni-solar forces move a volume of water from any part of any

meridian, the vis-inertiæ of the ocean carries an exactly equal volume to some other part of that same meridian. And so, also, if the luni-solar forces move a volume of water from any part of any parallel of latitude, the vis-inertiæ of the ocean carries an equal volume of water to some other part of the same parallel of latitude. Thus, therefore, as the tidal undulations caused by the luni-solar forces rise on any meridian in the equatorial regions, there is a corresponding fall on that same meridian in the temperate zones: and as the tide falls on any meridian in the equatorial regions it rises on the same meridian in the temperate zones. Thus the action of vis-inertiæ resulting from the earth's axial rotation causes the tides to move westwards in the equatorial regions and eastwards in the temperate zones, just in the same manner as that in which it causes the oceanic circulation described in Book II.

This action is the same as regards both the solar and the lunar tides, because it acts upon them according to their position in the ocean, and is in no way concerned with the cause of their being raised in one part of the ocean rather than in another: it simply determines their movements in relation to the surface of the earth, and is not concerned with what the cause of the tide may be. And for just the same reason that any given mass of water which the earth's gravitation tends to hold in any part of the ocean is carried through the oceanic circulation

before described, so also that which the gravitation of the sun or moon tends to place in any given part of the ocean is carried through the same course in relation to the surface of the earth. The fact of the moon's gravitation drawing the tide eastwards from below the moon, and the sun's gravitation drawing the solar tide westwards from below the sun, has nothing to do with the course of the tide through the ocean after it has been raised by either of those forces. After it is placed in any part of the ocean it is carried from that part, through the course of circulation which vis-inertiæ determines, without reference to whence it came, just as water placed in any part of the ocean by the earth's gravitation is carried through the same course of circulation without reference to whence it originally came.

Whatever the positions of the sun or moon in relation to any given meridian may be, their gravitation forms a part of the current-creating force of vis-inertiæ, acting westwards on that meridian just as much as on any other meridian. The tidal action of the sun and moon is, therefore quite distinct from the current-creating action of vis-inertiæ, though the gravitation of the sun and moon is merged in, and forms a part of, this current-creating force of vis-inertiæ.

The tides, as they are broken by the coast-lines, are constantly being thrown into the course of the ocean currents resulting from the action of vis-

inertiæ, though ocean currents and tides are movements of distinctly different natures.

The ocean currents, as already shown, result from the great cosmical force of gravitation drawing in all directions from the centre of the earth, opposing terrestrial gravitation drawing towards the centre of the earth; and they form a system of circulation within the position in which the ocean is held by gravitation, without tending to cause any changing of the position of the ocean in relation to the surface of the earth; and these ocean currents would exist even if the earth were not affected by the gravitation—or by any other influence—of the other bodies of the solar system: whereas, the tides result from the disturbing influence of the bodies within the solar system, which cause a constant changing of the position of the ocean, in accordance with the changes in their positions in relation to the surface of the earth; but the movements which form the tides are undulations or oscillations of the ocean, and not currents, though, where obstructed by coast-lines, they form currents about the coast.

The current-creating action of vis-inertiæ is the cause of the currents by which the circulation of the ocean is effected, and must form the basis of any effective investigation of the tides; for the study of the tides is, in fact, a branch of the study of vis-inertiæ, and it is not possible to trace out and explain the tidal movements of the ocean without the

assistance of the theory of vis-inertiæ, which must reveal the course of the earth's onward motion in the universe, as it has revealed the abstract nature of the forces by which it is held in equilibrium as it sweeps along the path determined by those forces.

BOOK V.

AN INVESTIGATION OF OCEAN CURRENTS.

SHOWING

THAT A CIRCULATION ACCORDING WITH THE ACTION OF VIS-INERTIÆ, DESCRIBED IN BOOK II., EXISTS IN THE OCEAN.

CHAPTER XI.

EVIDENCES OF THE CURRENT-CREATING ACTION OF VIS-INERTIÆ, RESULTING FROM THE AXIAL ROTATION OF THE EARTH.

PART I.

EVIDENCES OF THE EXISTENCE OF THE CURRENTS DESCRIBED AS ENCLOSING THE OCEANIC DISTRICTS SHOWN ON THE CHARTS ON PLATES I. AND II.

In the equatorial regions, from the eastern parts of the Pacific Ocean, there is a constant motion of the ocean westwards; and the water carried westwards by this motion is as constantly replaced by currents flowing towards the equator from the directions of California and Chili. In the western part of the Pacific, the water brought to that part of the ocean through the equatorial regions is poured northwards and southwards from the equator, a portion also continuing its westward course through the channels leading into the Indian Ocean.

The water turned northwards from the equatorial regions in the western part of the Pacific Ocean meets, near the Japan Islands, with a stream of cold

water flowing from the north. The supply of water brought by these streams to the temperate zone on the western side of the ocean is carried eastwards through the temperate zone, forming a constant stream, which, in the neighbourhood of the coasts of Oregon, divides northwards and southwards; the former portion flowing towards Russian America, the latter towards the equator.

In the North Atlantic Ocean the general course of the currents is similar to that just described as existing in the North Pacific Ocean—namely: westwards in the equatorial regions; northwards from the equator to the temperate zone on the western side of the ocean; southwards from the temperate zone to the equatorial regions on the eastern side of the ocean; eastwards through the temperate zone. In the temperate zone on the western side of the ocean, the warm water flowing from the equatorial regions meets a stream of cold water flowing from the north; and the water which flows eastwards through the temperate zone divides northwards and southwards in the eastern parts of the ocean—the one portion flowing southwards past the Cape Verde Islands, the other flowing northwards to the east of Iceland.

We have seen that the westward motion through the equatorial regions of the Pacific is continued in the Indian Ocean. In this ocean a further supply for the westward course of the waters in its equatorial

regions is brought from the south temperate zone by a stream flowing northwards along the western coast of Australia. The water carried westwards in the equatorial regions flows southwards, on the western side of the ocean, from the equator towards the Cape of Good Hope. Near the Cape of Good Hope it meets cold water from the south. From this, through the temperate zone, the water flows eastwards towards Australia, where a portion of the eastward stream turns northwards, flowing towards the equator on the eastern side of the Indian Ocean—the remainder flowing on eastwards towards the South Pacific. Through the temperate regions of the South Pacific, the water constantly flows eastwards towards the coast of South America, where, in the neighbourhood of the southern parts of Chili, the stream divides—one portion flowing northwards towards the equator, the other flowing southwards towards Cape Horn, from which it flows northwards and eastwards into the South Atlantic.

In the equatorial regions of the Atlantic the great mass of the water heaves westwards as in the Pacific. In the eastern part of the South Atlantic, as in that of the North Atlantic, the water flows from the temperate zone towards the equator, forming a supply for the great westward motion of the water in the equatorial regions. From the equatorial regions in the western part of the ocean, in the neighbourhood of Cape San Roque, the water brought westwards

divides northwards and southwards; the latter flowing from the equator to the temperate zone through the western part of the South Atlantic, as we have seen that the portion turned northwards does through the western part of the North Atlantic. Through the temperate zone of the South Atlantic the water flows eastwards, as through the temperate zone of the North Atlantic.

Thus far we have given the general features of the circulation of oceanic currents, as far as has been so clearly ascertained by experience as to be no longer questions of controversy. And the course of the currents, as far as described in this sketch, will be observed to be in close accordance with that of the currents which, under the theoretical action of vis-inertiæ described in Book II., tend to form the oceanic districts shown in the chart on Plates I. and II. of this volume, and also in Plate VI.

It is well known that in the Great Southern Ocean a current flows northwards from the Antarctic regions of the Pacific, bringing with it icebergs, which, on reaching the eastward current already described, are carried eastwards towards Cape Horn; and a similar movement of icebergs towards the Cape of Good Hope from the Antarctic regions of the Atlantic appears to indicate the existence of a northward current from the Antarctic regions of the Atlantic analogous to that which flows from the Antarctic regions of the Pacific. Those portions of

the Great Southern Ocean which lie just west of each of these ice-bearing currents are found to be comparatively free from ice, as is shown by the useful and interesting chart of the Antarctic Ocean recently published by the Admiralty. The absence of icebergs in the parts of the ocean just mentioned appears to indicate a southward motion of the water preventing the ice from moving northwards in those parts of the ocean. The currents, to and from the Polar regions, which may be inferred from these movements of the icebergs, are clearly in accordance, both as regards their relative positions and directions, with those described theoretically as resulting from the action of vis-inertiæ, and shown in the charts on Plates I., II., and XI.

As the current which, according to the theoretical action of vis-inertiæ, runs westwards from the Atlantic to the Pacific has not been found to exist passing north of Graham Land, it must, according to that theory, pass through the unexplored regions lying between Graham Land and the land (supposed to be portions of an Antarctic Continent) discovered in the voyages of exploration under Captain Wilkes and Sir James Ross. The phenomena of the icebergs above referred to clearly accord with that which is theoretically indicated as the course of the current in question. It keeps open a comparatively clear seaway in its course southwards from the Atlantic to the Antarctic regions, and, after sweeping

the Antarctic coast, it flows northwards into the Pacific with its temperature reduced, and laden with icebergs from the frozen regions of the South.

The accordance of the Antarctic currents with the theoretical action of vis-inertiæ is further corroborated by the observations of Sir James Ross and by those of Captain Wilkes. The former found the current running southwards off the coast of South Victoria; and the latter, who sailed westwards in the Antarctic regions of the Indian Ocean, along what he supposed to be the shores of an Antarctic Continent, says that the movements of the ice detached from the supposed coast-line appeared to indicate a motion of the water westwards and northwards. The remarkable accordance of Captain Wilkes' observations on the movements of the ice in those regions with what would naturally result from the action of vis-inertiæ in case of a coast-line existing there, appears to me to leave no doubt of the existence of a sufficient extent of land in those regions to form an 'Antarctic Continent.'

PART II.

EVIDENCES OF THE EXISTENCE OF THE EQUATORIAL COUNTER-CURRENTS.

We have thus far found the currents which enclose the districts shown on the charts as theoretically resulting from the action of vis-inertiæ to be in accordance with actual observation.

In Book II. we described the tendency of the action of vis-inertiæ to cause a counter-current to run eastwards in the equatorial regions, dividing the waters which tend to diverge northwards from those which tend to diverge southwards from the equator. In the Pacific, as might be expected from the configuration of the coast on the western side of the ocean, such a counter-current is clearly developed. And this Pacific counter-current appears to be a remarkable illustration of the amount by which the current-creating action of vis-inertiæ exceeds that of the winds ; for, of any quantity of water blown towards the equator from the north-east and south-east by the Trade Winds, a portion would naturally tend to return eastwards through the belt of equatorial calms, where it is released from the action of the winds which have impelled it westwards : but this counter-current appears, as far as I have ascertained, to run through the region of the NE. Trade Wind ; whereas the action of the winds might have been expected so to modify the natural action of vis-inertiæ as to compel it to make its way eastwards through the calm belt, where the action of the winds, instead of opposing, would rather, as shown above, tend to assist it on its course.

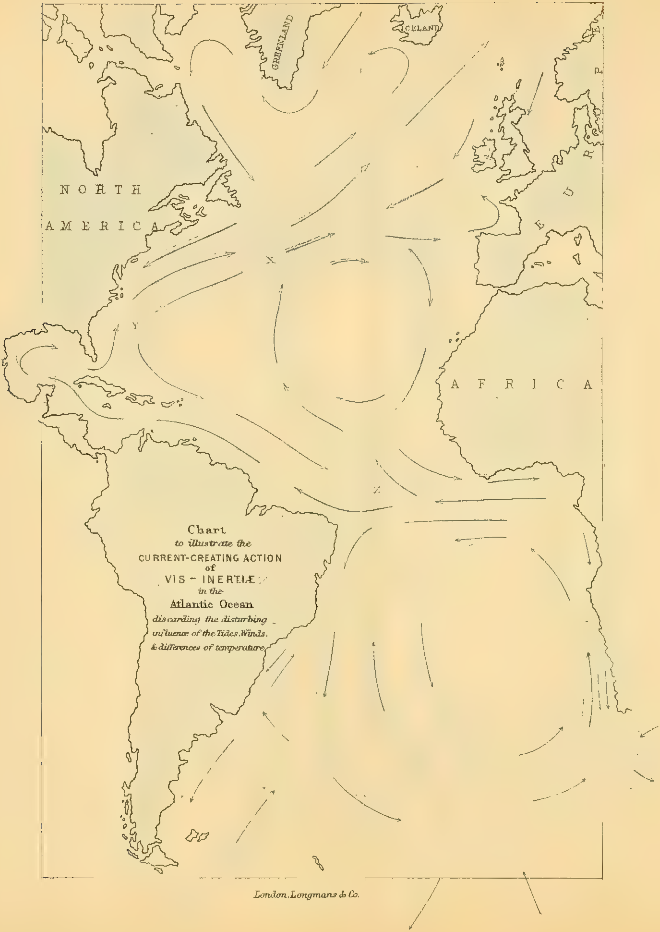
In the Atlantic, the configuration of the coast projecting eastwards in the equatorial regions must prevent a counter-current analogous to that of the Pacific from being developed to more than a very trifling

extent; and if observable at all, it must appear as an inshore eddy, or as a stream from the Amazon River. That which is shown as the equatorial counter-current of the Atlantic is contained within the north equatorial district of currents, and is not (as in the Pacific) a current dividing the north from the south equatorial district. In consequence of the peculiar configuration of the coast of Africa, the current which runs from the temperate zone to the equator on the east side of the ocean runs eastwards during a great portion of the latter part of its course to the equator. And also the difference in the configuration of the oceans causes an eastward current to be very largely developed within the North Atlantic district which is developed to a comparatively trivial extent in the South Atlantic district. The evidences of the existence of these eastward currents must, therefore, be considered in connection with the investigation of the currents contained within the North Atlantic district.

PART III.

EVIDENCES OF THE EXISTENCE OF THE CURRENTS THEORETICALLY DESCRIBED WITHIN THE OCEANIC DISTRICTS.

The chart of the Atlantic given on Plate XV. is drawn to illustrate the action of vis-inertiæ within the equatorial districts. Let us consider what traces of the existence of currents of the nature we have



London, Longmans & Co.

described have been observed within the North Atlantic district.

Speaking of the Atlantic Equatorial Current, Major Rennell says that—'At the middle point between the two continents, and precisely at the equator, the stream sends off a very large branch to the north-west, and into the midst of the North Atlantic; whilst the main stream turns to the west-south-west, pointing to the promontory of Cape San Roque: and, when it approaches that Cape, it subdivides; the largest part passing by the north of the Cape, towards the West Indies; the other southward, along the eastern coast of Brazil.' [1]

The stream mentioned in the first part of the foregoing extract as diverging north-westwards into the North Atlantic is clearly in accordance with the current O R, described theoretically in connection with Plate IX., as resulting from the action of vis-inertiæ. Of this current, Major Rennell says farther on: 'The north-west branch of the equatorial current, which separates in about longitude 23°, as aforesaid, is traced, at common times, as far north as 18°, and sometimes even as far north as 30°. It appears to be, at least, eighty leagues in breadth, but not of rapid motion (perhaps less than one knot at a mean), and runs nearly in the direction which the

[1] *An Investigation of the Currents of the Atlantic Ocean*, by Major James Rennell, F.R.S. (London, 1832), p. 23. All following quotations from Major Rennell are taken from the same work.

NE. Trade admits ships to take; in their progress northwards it is often a great help.'[1] And then Major Rennell remarks: 'I am unable to account satisfactorily for the cause of this great derivation from the great *trunk stream* of equatorial current, unless it be to supply the waste of water, by evaporation, within the tract occupied by the *warm* water of the Gulf Stream—in effect its *recipient*—and the supply of the Mediterranean Sea.'

As the stream here described runs right across the NE. Trade Wind, it is naturally a stumbling-block in the way of a theory which makes the winds the great prime movers of the oceanic currents; for, if a stream of this sort run right across the NE. Trade Wind, it is not easy to see how the Trade Winds can be the great prime cause of the Gulf Stream, which does not itself run with the wind.

Although this stream has not been traced continuously beyond 30° N., we find, in another part of Major Rennell's useful work, further evidences of its existence in a course coinciding with the theoretical action of vis-inertiæ which we have described. Referring to a Report on Currents, Major Rennell says: 'An important notice communicated by it is the proof of a *counter-current of warm water*, of 13 to 21 miles, running to the westward, and along the south side of the main stream (the Gulf Stream), between the parallels of 35° and 36°. This is the second example of the same kind, Captain Livingston

[1] P. 115, *ib.*

having experienced a like current in latitude 39°, and between the meridians of 55° and 62½° W.' [1] And in a note farther on Major Rennell says further of this current: 'A counter-current of *warm water*, reported by Captain Livingston, in such a position as to appear a kind of *anomaly*, in our present imperfect state of knowledge, has been already spoken of at large. From the weight of authority, the fact cannot be questioned. It may be sufficient in this place to state that the current, running W. by N. more than 100 leagues, occurred between the parallel of 38° 50′, long, 62½°, and lat. 39° 20′, long. 55°.' [2]

The warmth of the water in this observed current is of importance, because, but for its temperature, it would have been at once asserted that it came from the Azores. It, however, clearly coincides with the current E (in Plate IX.), diverging westwards, to turn southwards, from the point X, at which the stream OR meets the stream A B C. And, in fact, this water comes from the equator by a shorter route than that of the Gulf Stream, which it must meet a short distance west of the longitude in which it was observed by Captain Livingston. The current here reported appears to indicate that the main stream O R meets the stream A B C in mid-ocean, east of the position in which the current in question was observed; for, as the stream A B C, flowing from the equator, tends eastwards, and the offset E, turned

[1] *Ib.* p. 228. [2] *Ib.* p. 253.

towards the equator, tends westwards, the latter must tend to run as a counter-current parallel to the course of the former, until its natural course westwards towards the equator is at length obstructed by the course of the stream A B C. The point at which the obstruction occurs forms the theoretical point Y, from which the offset H is forced eastwards towards the equator between the main streams O R and A B C.

As regards the evidences of the existence of the theoretical current H on Plate IX., which is also illustrated in the Chart on Plate XV., Captain Livingston, as quoted by Mr. Findlay, says: 'I have no doubt that there is a current, or rather offset, from the Gulf Stream to windward, between Bermuda and the Bahamas. In the "Brilliant," we found ourselves retarded very much in making westing when running for the Hole-in-the-Wall, one day, about 30 miles of longitude, by excellent observations, the truth of which was confirmed by our land-fall. In the "Dispatch" we got out of the Gulf on the 13th of March, 1819, when we were at noon, by observation, in lat. 28° 0′, long., by account, 79° 12′; on the 20th of March, at noon, we were, by meridian altitude, in lat. 29° 48′, and long., by account, 72° 32′. Observations by sun and moon, a good lunar of three sights, altitudes, and distances, and worked three times, gave 71° 18′ 30″.'[1]

[1] *Memoir descriptive and explanatory of the Northern Atlantic Ocean*, by John Pürdy. Twelfth edition, by Alexander G. Findlay, F.R.G.S. (London, 1865), p. 333.

The current here observed by Captain Livingston must not, without authority from actual observation, be confounded with an inshore current running from the Gulf Stream just north of the Bahamas. For this latter may be an eddy-current, contained within the theoretical current A B C (Plate IX.), and caused by the islands which divide that current into two portions ; the greater portion passing south of the islands, and the other portion north of them—if, indeed, at any season the volume of A B C be too great to pass within the islands—in which case, when the eddy-current exists, then the portion of the current A B C, of which the eddy-current is an offset, should be found running north-westwards between that and the Bermudas : but this is a question to be decided by observation, not only in the current itself, where it is strong enough to make itself manifest, but also, in order to determine its nature, whence it comes and whither it goes, the actual course of the principal theoretical current O R and its variations must be better determined by actual observation ; for shallow water, if the bottom be rock or firm ground, may be little less important in determining the course of the currents within any district than actual land. And, indeed, by the configuration of the bottom of the ocean in the neighbourhood of the Bermudas, a portion of the cold water, which, under the theoretical action described in Book II., endeavours to pass by an under-current from the

Labrador Current to the eastern part of the equatorial regions of the Atlantic, appears to be forced to the surface of the ocean near the Bermudas—thus appearing at the surface immediately after under-running the Gulf Stream. Recorded observations, which we shall have to mention farther on, appear to show that, in general, the whole volume of the theoretical current A B C passes inside the Bahamas, though not all through the Gulf of Mexico.

The theoretical current H has also been observed farther on its course towards the equator, though it has been accounted for by Mr. Findlay in a manner which, if there were no other reasons for discarding the theory which makes the action of the winds the principal current-creating force, would be most natural. In the North Atlantic Memoir, Mr. Findlay says, 'It has been found that during calm weather, even with strong easterly winds, the currents have sometimes been running for days together to the eastward, especially in the latter parts of January and July, when, by the then prevailing strong winds, the water is heaped up in a very uncommon degree, and the inner part of the Caribbean Sea, most probably overcharged, succeeds in re-establishing its equilibrium by forsaking the power of its wrathful driver. In this manner, I think, we ought to reconcile those circumstances.' [1]

But considering how greatly the action of vis-

[1] *Ib.* p. 306.

inertiæ, according to the phenomena before mentioned, exceeds that of the winds, and the manner in which its action in the ocean, indicated by the oblate spheroidal form of the earth, is corroborated by the arguments in Book III., it is scarcely too bold to suggest that this current may at times be found distinctly running eastwards when there is no eastward current running from the Caribbean Sea; or even when the currents are as distinctly running westwards into the Caribbean Sea through all its western channels. In this—perhaps an extreme case, and suggested only for the sake of illustrating the theory—the currents running westwards into the Caribbean Sea would be supplied by the equatorial current along the northern shore of Brazil, and by a current running south-eastwards from the direction of the Bermudas, and afterwards curving southwards and westwards to those channels. These two currents, on uniting to flow into the Caribbean Sea, would represent the theoretical current A B C in Plate IX. As to whether the whole of the theoretical current A B C passes through the Caribbean Sea, or only a portion of it, the remainder passing north of the Antilles, is a question which can be decided only by actual observation.

This eastward current (H, Plate IX.) is also mentioned by Captain Richards, in a paper published by the Admiralty, in which Captain Richards says: 'To the eastward of 40° W., part of this easterly

current approaches nearer to the equator, or to about 2° N., and decreases considerably in strength, until joining the Guinea Current, where it increases again in velocity as it nears the African shores.'[1] That the current observed running eastwards in the western parts of the ocean is not the same as that which runs eastwards in the eastern parts of the ocean appears from what Captain Richards says in the same paper—namely : 'This *counter-current* has been traced to extend, at certain months of the year, from the meridian of 53° or 50° W. to that of about 25° W., and thus joining or forming a part of the well-known Guinea Current. It is seldom experienced to the southward of 2° N.,' &c

Now, that this current should have been traced as far as 25° W., accords perfectly with the current theoretically described ; and that, when the equatorial belt of calms is in the same latitude as the eastward currents in question, water carried westwards towards the equatorial calm belt by the Trade Winds may escape eastwards in the belt of calms, and so temporarily effect a union on the surface of the currents, appears probable enough ; but that the currents are intrinsically different and independent of one another appears from the fact of the existence of the current described by Major Rennell, branching off *precisely* on the equator north-westwards, in latitude 23½° W.

[1] *Notice to Mariners—Atlantic Ocean Currents near the Equator.* Hydrographic Office, Admiralty (London, 1866).

As this north-westward current branches off from the great westward current of the equatorial regions, it obviously divides the counter-current running eastwards in the western parts of the ocean from the Guinea Current running eastwards in the eastern parts of the ocean.

I have noticed that a peculiarity in the configuration of the bottom of the ocean appears to be the cause of a portion of the great North Atlantic under-current being forced to the surface of the ocean in the neighbourhood of the Bermudas. And, considering the great mass of reported currents mentioned in Mr. Findlay's North Atlantic Memoir, it would appear that the theoretical current E (Plate IX.) is displaced from what would otherwise be its natural course, in consequence of this same obstruction. This appears to be so for the following reasons.

Speaking of the Sargasso Sea, Mr. Findlay, in the North Atlantic Memoir, says that he is 'assured, from the comparison of a great number of journals, that in the basin of the North Atlantic Ocean there exist two banks of weeds, very different from each other; the most extensive is a little to the west of the meridian of Fayal, one of the Azores, between lat. 25° and lat. 36°:' the second 'occupies a much smaller space between the 26° and 22° of latitude, eighty leagues east of the meridian of the Bahamas.'[1] Such a

[1] *Memoir Descriptive and Explanatory of the Northern Atlantic Ocean*, p. 292.

division of the Sargasso weeds may be taken to indicate the course of the theoretical stream O R; the central part of that current making a clear way for itself by throwing off the weeds on both sides into the more slowly-moving portions of the rotating currents on each side of it. If these floating weeds thus indicate the course of the stream O R, it must then also be inferred that the theoretical stream E lies west of the smaller or western portion of the floating weeds; these weeds being encircled by the stream O R, and the counter-streams E and H. And, in fact, numerous observations show a setting of the water from the border of the Gulf Stream south-eastwards towards the Antilles; though the connected course of the counter-streams E and H, and the natural position of the theoretical point Y, appear to be interfered with by the intruding under-current, which we have mentioned above as appearing to be forced to the surface near the Bermudas. In this case, from the north of the Antilles, the theoretical current H must continue its course eastwards and south-eastwards towards the equator, between the mid-ocean current and the equatorial current, both running in the opposite direction.

This gives a circulation in accordance with the theoretical action of vis-inertiæ described in Book II. in connection with Plate IX., and also in accordance with recorded observations, excepting that the course of the counter-current is not very satisfactorily

traced from the point X, where the Gulf Stream meets the mid-ocean stream, to the Antilles ; but this I have suggested is in consequence of the intrusion of the under-current, which deranges the circulation of the surface currents in that part of the ocean.

I do not find any recorded observation to indicate that the current E, at any season of the year, takes a southward course passing east of the Bermudas ; and also, if it ever take such a course, a current running north-westwards midway between the Bahamas and the Bermudas must almost necessarily be concomitant with it ; and for this I find no authority either.

Let us now briefly recapitulate what, according to the foregoing investigation, appears to be indicated, alike by theory and observation, to be the general circulation within the equatorial district of the North Atlantic Ocean.

From the equator, in mid-ocean, a stream runs off north-westwards into the North Atlantic. The projecting coast of Africa causes the stream which encircles the district, returning to the equator on the east side of the ocean, to press down upon the north-westward stream, which latter forms a barrier preventing the southward stream from falling westwards. The north-westward stream, as it flows through the ocean, clears a way through the Sargasso Sea, thrusting the weeds off to both sides of its course. The current O R, diverging north-westwards from the

equator, has, as already explained, a tendency to turn more and more northwards as it proceeds on its course; and the current A B C meets it in mid-ocean, south of lat. 40° N. From the meeting-point (X) the offset northwards is carried eastwards; which is the course which the current O R would itself, sooner or later, have taken, even if not interfered with by the current A B C: and the offset southwards (E), being under that influence of change of latitude which tends to carry it westwards, runs as a counter-current along the right-hand side of the stream A B C until the course of the latter forces it eastwards, forming the eastward current H from the point Y to Z, so that the streams E and H form a continuous counter-current, running from the point X, at which the stream O R meets the stream A B C, first westwards and then eastwards, along the right-hand side of the stream A B C to the point Z, at which the stream O R diverges from the equator. The connected course of this counter-current appears to be interfered with by the upheaval of an under-current, forced to the surface by some peculiarity in the configuration of the ocean in the neighbourhood of the Bermudas; but it has been recorded running westwards counter to the Gulf Stream from about mid-ocean south of lat. 40° N.: then setting south-eastwards, from the Gulf Stream, between the Bermuda and the Bahama Islands: and again running south-eastwards, from the direction of the West Indies towards the equator in mid-

ocean. It often forms a rapid current, running eastwards north of the Virgin Islands. These appear to be the normal currents within the district, though varying their position and velocity with the seasons, and, at intervals, to a greater or lesser extent obliterated by the action of gales and other causes.

Now, if the currents of the North Atlantic Ocean are such as here described, then does not that stream flowing from the equator through mid-ocean towards the banks of Newfoundland explode the theory which makes the winds the cause of the great oceanic currents? Does it not explode any theory which makes the winds the principal cause in determining the *course* of the currents,—even supposing the principal *motive force* to result from the inequalities in temperature and other conditions between the polar and equatorial regions? A theoretical consideration of the action of vis-inertiæ shows that it must tend to cause such a current: and the investigation of recorded phenomena shows evidences of its actual existence; and therefore, as it runs its course and forms its counter-currents in a manner according with the laws indicated by that theory, it must be admitted as a proof of the paramount action of vis-inertiæ in the ocean, at least until some other reasonable explanation of its existence be given.[1]

[1] Evidence of the existence of the current E H in the North Pacific, the South Pacific, and the South Indian Oceans is more clear than above shown for the North Atlantic.

CHAPTER XII.

EVIDENCES OF THE CURRENT-CREATING ACTION OF VIS-INERTIÆ RESULTING FROM THE ONWARD MOTION OF THE EARTH THROUGH SPACE.

PART I.

GENERAL EVIDENCES OF ONWARD MOTION.

In the theoretical consideration of vis-inertiæ, I have in Chapter III. described the variations in the direction of the action of the orbital force of vis-inertiæ, showing a daily variation through fourteen points of the compass, and an annual variation through four points, the daily variation being from an action westwards in the night-time to an action eastwards in the daytime, and the annual variation being from an action northwards in March to an action southwards in September.

Now, on examining the actual movements of the ocean, although there appear such effects as may be expected, in accordance with the theoretical action of vis-inertiæ, to result from an onward motion of the earth, these effects do not accord with that indicated theoretically as the action of vis-inertiæ

resulting from the orbital motion. But, variations in the effects alluded to as being in accordance with what the theoretical consideration of the action of vis-inertiæ indicates to be the natural result of an onward motion of the earth, appear to show that the orbital force is a partial cause of the effects observed.

For instance, the effects apparent in the ocean, instead of showing an annual change in the action of vis-inertiæ from a northward to a southward direction, indicate a constant action northwards ; though at the same time an annual variation in the northward action, by which its action in March is greater than in September, appears to show the influence of the orbital force.

And also, as regards the diurnal variation in the action of the orbital force, there is not apparent such a reversal from eastwards in the daytime to westwards at night-time as that which the sole action of the orbital force would tend to cause. But there are, however, apparent effects which indicate such a change from an eastward action in the daytime to a westward action in the night-time as accords with the onward motion indicated by the northward action and its variation above mentioned. Because in such case the orbital motion being only a component of the earth's true motion, and the latter being not in the plane of the ecliptic, but inclined southwards, more in the line of the poles ; then, instead of a diurnal change from east to west through

fourteen points of the compass, the diurnal change in the action of the force resulting from onward motion would be less in proportion as the direction of the motion more nearly coincided with the line of the poles. If the line of motion coincided exactly with the line of the poles there would then be no variations whatever in the action of the force resulting from that onward motion; but its action throughout the year, both by day and night, would be northwards through mid-ocean and southwards along the shores.

In the ocean, effects in accordance with the action theoretically resulting from an onward motion of the earth indicate a motion southwards; and variations both annual and diurnal appear to indicate that, though the line of motion does not coincide with the line of the poles, the divergence of those lines is not very great.

The action of vis-inertiæ resulting from the onward motion of the earth appears to be indicated in the Atlantic by a greater tendency of the currents in mid-ocean to run northwards, and of those along the coasts to run southwards, than accords with the action of vis-inertiæ which results from the axial rotation of the earth. For instance, the current which diverges northwards from the equator in mid-ocean under the action of axial rotation, as before described, we have found to be clearly recorded; whereas

I do not find that the analogous divergence southwards has been noticed, and it is only by means of observations which accord with the course of its counter-currents that I find any recorded trace of its existence. And, as regards the coasts, the stream which runs southwards from the Arctic regions on the west of the ocean shows a remarkably constant tendency to keep inshore during the whole of its course from the east coast of Greenland to the coast of Florida: it being, in fact, forced inshore both by the action resulting from axial rotation and by that resulting from onward motion. But the stream from the Antarctic regions, analogous, as far as axial rotation is concerned, to the Arctic stream just described, appears to be drawn from the direction of Cape Horn eastwards towards mid-ocean, though the sole action of axial rotation would tend to throw it inshore from Cape Horn, and cause it to run northwards along the east coast of South America [1] in the same manner as that in which it tends to throw the Arctic stream inshore against the coast of North America; instead of which the stream from Cape Horn bears eastwards, leaving a great eddy to run southwards between it and the shore.

[1] The 'Challenger' explorations have shown the existence of a greater mass of cold water moving northwards below the surface in that locality than was apparent in 1868, when the above was published. But the corresponding stream in the northern hemisphere is much more apparent on the surface, as stated in the text above, which those explorations corroborate.

The tendency of this Antarctic stream to take its northward course through mid-ocean, compared with that of the Arctic stream hugging the shore in its southward course, accords with what would naturally be the action of vis-inertiæ resulting from a southward motion of the earth. For we have seen that the action of such a force tends to circulate the waters northwards through the deep and central parts of the ocean, and southwards along the shores. This action appears to be again exemplified on the east of the ocean by the frequent occurrence of a stream southwards from the equator along the west coast of Africa; the northward stream from the direction of the Cape of Good Hope being drawn towards mid-ocean, whilst the southward stream runs between it and the coast.

PART II.

EVIDENCES OF VARIATIONS ACCORDING WITH THE VARIATIONS IN THE COURSE OF THE EARTH'S ORBITAL MOTION.

As regards that annual variation in the tendency of northward streams towards mid-ocean, and of southward streams towards the coasts, which appears to indicate the influence of the earth's orbital motion, tending to make the northward action of vis-inertiæ more decided in March than in September: it appears

to be exemplified by the Arctic stream, which runs southwards on the North American coast, thrusting the Gulf Stream farther from the coast in March than in September. These currents have been more elaborately investigated than any other great ocean currents, and the annual variation here mentioned accords with the idea of its being influenced by the earth's orbital motion ; but I have not met with any other recorded variations of ocean currents that appear sufficiently definite to be adduced as indicating the action of the same cause.

As regards the diurnal variation which, if the line of motion be not coincident with the line of the poles, must result from the action of vis-inertiæ being west of north in the night-time and east of north in the daytime ;—the phenomena of winds in given localities having a different average direction in the night-time from the average direction in the daytime are in accordance with such a cause ; though I know of no recorded phenomena that can be clearly traced in its action, as alterations in the relative temperature on land and water tend to produce the same effect. The Straits of Gibraltar appear well adapted for ascertaining the diurnal variation in the orbital force of vis-inertiæ, as the tendency of its action would be to cause a current westwards from the Mediterranean in the night-time, and eastwards from the Atlantic in the daytime ; and therefore the current may be expected oftener to take a westward

course from the Mediterranean during the night-time than during the daytime. On the only occasion on which I have passed through those straits, instead of the current usually running eastwards, a strong current was running westwards from the Mediterranean, and that was during the night-time.

These remarks on the annual and diurnal variations possibly resulting from the action of the orbital force would not be ventured on but for the clear manner in which the evidences of the action of vis-inertiæ, resulting from axial rotation and onward motion, accord with that indicated by the theoretical consideration of their action.

BOOK VI.

AN INVESTIGATION OF THE TIDES

SHOWING

THAT THE TIDAL MOVEMENTS OF THE OCEAN ACCORD WITH THE ACTION OF THE FORCES DESCRIBED IN BOOK IV.

CHAPTER XIII.

EVIDENCES OF THE TIDAL ACTION DESCRIBED IN CHAPTER X.

PART I.

THE MOTION WEST IN THE EQUATORIAL REGIONS AND EAST IN THE TEMPERATE ZONES.

THE action of the forces described in Chapter X. as tending to give the tide-waves a motion westwards in the equatorial regions and eastwards in the temperate zones, is indicated by the following observations, in a most useful paper, relating to the subject of the tides, by the late Admiral Fitzroy.

Referring to the times of high water on the days of full and new moon, and giving all the tidal hours in Greenwich time, Admiral Fitzroy says: 'It is high water at the east side of the Atlantic, from the Canary Islands to Scotland, within an hour or two of the same time, on the salient points of the coast, namely at about 4^h.'[1] This clearly accords with the eastward course of the tide-wave through the temperate zone.

[1] *The Weather Book: a Manual of Practical Meteorology*, p. 384. By Rear-Admiral Fitzroy. London, 1863.

On the west of the ocean: 'It is high water at about 1^h from 30° to 40° N.'[1] This accords with the tide which rolls from the east through the equatorial regions. But Admiral Fitzroy goes on to say: 'The times increase northwards from 40° N. to the Bay of Fundy, and also southwards from 50° N. to that bay.'[2] The times increasing northwards from 40° N. to the Bay of Fundy shows the eastward motion of the tide in the temperate zone, and the times increasing southwards from 50° N. appears to accord with the configuration of the coast, which causes the portion of the tide drawn eastwards from the coasts of Labrador to interfere with that drawn eastwards from the coast of the State of New York.

'It is high water at 6^h on the coast of Brazil, and at 9^h about Blanco Bay (in 40° S.).'[3] This shows the equatorial tide rolling westwards, and then turned southwards by the coast.

'From 50° S. to near Blanco Bay, in 40° S., the tide-wave certainly travels along the coast to the north.'[4] This accords with the tide which rolls eastwards through the temperate zone of the southern hemisphere, and sets northwards along the coast of Patagonia after rounding Cape Horn, but at the same time tends to follow its eastward course through the temperate zone of the South Atlantic Ocean.

Admiral Fitzroy speaks of 'the flood-tide moving

[1] P. 384. [2] P. 384. [3] P. 383. [4] P. 382.

towards the west and south along the coast of Brazil, from near Pernambuco to the vicinity of the River Plate,' and also of 'the almost uniformity of the time of high water along that extent of the coast of Africa which reaches from near the Cape of Good Hope to the neighbourhood of the Congo.'[1] The former we have already mentioned, as indicating the equatorial tide moving westwards and then turned southwards by the coast; the latter accords with the tide rolling eastwards in the temperate zone.

'Against the supposition that a tide-wave travels along the west coast of America, from south to north, are the facts—that the flood-tide impinges upon Chilóe and the adjacent outer coast, from the southward of west; that it is high water at Cape Pillar and at Chilóe, including the intermediate coast, almost at one time; that from Valdivia to the Bay of Mexilones (differing 18° in latitude), there is not an hour's difference in the time of high water; that from Arica to Payta the times vary gradually as the coast trends westward; that from Panama to California the times also change gradually as the coast trends westward; and that from 40° to 60° N. high water takes place at one time.'[2] These facts accord with the tides rolling eastwards through both of the temperate zones of the Pacific.

'In 50° N. it is high water at Vancouver's Island at 9^h, and at the south extreme of Kamtschatka it

[1] P. 371. [2] P. 371.

is *said* to be high water at about 6^h; the difference, nine or three hours, is anomalous—made so, probably, by a derivative tide, or by a mistake.'[1] But the tide which reaches Kamtschatka at 6^h must, out in the ocean, have then advanced considerably farther on its eastward course, and therefore the difference of 3^h between Kamtschatka and Vancouver's Island does not appear improbable.

'High water takes place at one time (within an hour) all along the east coast of Africa'[2]:—according with the tide moving westwards through the equatorial regions of the Indian Ocean.

The paper by Admiral Fitzroy, from which all the foregoing facts have been quoted, was written for the purpose of showing how incompatible the actual movements of the tides are with the theory which supposes the tides of the Atlantic Ocean to be caused by simply derivative waves branching off from a wave rolling through the Great Southern Ocean.

PART II.

THE EQUILIBRIUM OF THE TIDES.

That the tidal undulations—rolling westwards in the equatorial regions, and eastwards in the temperate zones—counterbalance each other, and thus preserve the equilibrium of the ocean as a whole, as regards

[1] P. 376. [2] P. 385.

the surface of the earth, appears to be indicated in the North Atlantic Ocean by the great height of the tides in the temperate zones compared with the rise and fall in the equatorial regions. For the water moved eastwards in the temperate zones is a counterpoise to that moved westwards in the equatorial regions by the same tide : and since the space from Nova Scotia to France and the British Isles, in which the eastward tide moves, is very narrow compared to that extending through the equatorial regions from the Gulf of Guinea to the Gulf of Mexico—therefore, since the tide in the east of the temperate zone must counterbalance that in the west of the equatorial regions, its rise and fall must be greater in proportion with the lesser extent of ocean through which it moves. So also with the tides in the west of the temperate zone, which counterbalance those in the east of the equatorial zone ; the rise and fall about Nova Scotia is far greater than that in the Gulf of Guinea, for the same reason that the rise and fall about the British Isles is greater than that about the West Indies. This counterbalancing movement of the tides is still more strikingly indicated by the contrast between the rise and fall in the temperate zone of the North Atlantic Ocean, compared with that in the temperate zone of the southern hemisphere. In the latter case the tide, which moves eastwards, has a more or less clear sweep from about the Falkland Islands and the River Plate to the

shores of Chili; and the rise and fall is less, in proportion as the space through which it moves is greater than that through which, in the equatorial regions, the same tide moves westwards. Thus, in the temperate zones of the South Atlantic Ocean (in the neighbourhood of the River Plate), the rise and fall of the tides is less than in the equatorial regions, because the space through which they move is greater than that of the equatorial tides which they counterbalance. In the South Pacific Ocean the tides, which roll eastwards in the temperate zones, have a considerable rise and fall against the shores of Patagonia, in order to counterbalance those which roll westwards, through the long extent of the equatorial regions, to the East Indies.

The action of the coast-lines in crowding the tide in some parts of the ocean more than in others, is seen on a smaller scale wherever parts of a tide are raised higher than other parts of the same tide by the crowding action of the coast-lines of bays and estuaries.

PART III.

CONVERGENCE TOWARDS THE EQUATOR.

In an ocean completely enveloping the earth the tide would, according to Chapter X., be an hour earlier on the average for each fifteen degrees of latitude as well as for each fifteen degrees of east longi-

tude ; for the tide travels down each meridian from the poles to the equator in about six hours. This convergence should be most apparent in high latitudes, in which the change in velocity of rotation is most rapid. And, in fact, it seems to be indicated in the North Atlantic by a southward course of the tide to the North of Scotland and Labrador, coalescing with the eastward course through the temperate zone ; and in the South Atlantic by the northward course along the coast of Patagonia of the tide which meets that coming down the coast of Brazil from the equatorial regions.

In the eastern part of the Pacific this converging action is sufficiently indicated by the extract on page 153 in which Admiral Fitzroy argues against the course of the tide-wave being from south to north ; for the preponderance of the eastward action in both of the temperate zones seems simply to make the convergence of the tides towards the equator more rapid than it would otherwise be, due allowance being made for the direction of the coast-line.

Throughout the Great Southern Ocean the motion along the meridians towards the equator is clearly indicated on Dr. Whewell's chart of co-tidal lines ; and though that chart professes to show a westward motion in the Great Southern Ocean to be the source of the North Atlantic tides, it gives evidence of the opposing motions of the tides westwards in the equatorial regions and eastwards in higher latitudes.

CHAPTER XIV.

EVIDENCE OF THE TIDAL ACTION DESCRIBED IN CHAPTER IX.

We have seen, in the preceding chapter, that the actual course of the tide-waves, in relation to the surface of the earth, accords with the theory which gives them a motion westwards in the equatorial regions, and eastwards in the temperate zones: that the relative rise and fall on different coasts accords with the theory which requires that the tide which rolls westwards in the equatorial regions must counterbalance that which rolls eastwards in the temperate zones, so as to preserve the equilibrium of the ocean as a whole; and that the advanced position of the tide in high latitudes is indicated by a convergence from those latitudes towards the equator.

As regards the hours of the spring-tides raised by the sun and moon in the positions given in Fig. 4, Plate XIII., we cannot, in consequence of the contortions of coast-lines, expect, without a very elaborate analysis of the subject, to arrive at more than rough approximation to the theory sketched in Chapter X.

Let us suppose that when the central part of the Atlantic, midway between the coast of America on the west, and that of Africa and Europe on the east,

is at the hour of 9 A.M., the tidal action of the luni-solar force is at its greatest point on the Atlantic, so as to make the undulation or vibration then formed the principal source of the tidal undulations vibrating through the Atlantic until the next action of a tide-raising force.

Now, when it is 9 A.M. in the central parts of the ocean, it is about 12 (noon) about the western shores of Europe. And as on the days of full and new moon, the high tides reach those shores at about 4 P.M and 4 A.M.,[1] the high tides two days after (when the solar and lunar tides are in conjunction) occur at about 6 A.M. and 6 P.M., low water occurring at the intermediate hours, which are those of noon and midnight: but when it is noon on the western shores of Europe, it is 9 A.M. about the central parts of the ocean. Thus the time of low water occurs at noon on the shores of Europe, because it is then 9 A.M. in the central part of the Atlantic, and the meridian of 9 A.M. and 9 P.M. is, approximately, that on which the combined action of the sun and moon tends to raise the high spring-tides about two days after full and new moon. When the lunar and solar forces which raised the tide in the centre of the ocean are withdrawn, it falls in the centre of the ocean, and rises on the shores. And since the hours of 9 A.M. and 9 P.M. are the times of high water in the centre of the ocean, the intermediate hours (which are those of 3 P.M. and 3 A.M.) are the hours

[1] P. 151.

of low water in the central parts of the ocean. But when it is 3 A.M. in the central parts of the Atlantic it is 6 A.M. on the western shores of Europe, which is, approximately, the actual time of high water on those shores two days after full and new moon.

We have also shown that when the action of the sun and moon passes west of the position in which it has raised a tide, it ceases to be a disturbing influence ; but the water, being placed in that part of the ocean by those or any other forces, is at once carried along with the course of the oceanic circulation caused by the action of vis-inertiæ. And by this action the tide is consequently carried from the central parts of the ocean eastwards in the temperate zones, and westwards in the equatorial regions, by the axial rotation of the earth ; and by the same action, in consequence of the onward motion of the earth southwards through space, the tide is carried northwards through the deep and central parts of the ocean, with a corresponding tendency southwards along the shores.

That the course of the tides thus indicated by theory is that which they actually follow, appears to be shown by the fact of high water occurring at almost the same time on the western shores of Europe and on those of Africa south of the equator ; and also by their having such a general tendency northwards, as well as to synchronise on opposite sides of the ocean, as to have led to the general acceptance of the theory which supposes a great tide-wave to follow the course of the sun and moon westwards through the Great

Southern Ocean, and to send off a branch northwards through the Atlantic, making the tides of the North Atlantic Ocean simply the effect of undulations caused three tides earlier in the Great Southern Ocean—the direct action of the sun or moon on the North Atlantic Ocean, in their intervening passages of the meridian, not being supposed to interfere with the progress of the tide-wave previously raised in the Great Southern Ocean. We need not here argue against this theory, for its non-accordance with actual facts has been sufficiently pointed out by Admiral Fitzroy, even supposing the course of the tide-waves through the great Southern Ocean to be westwards. Admiral Fitzroy, though objecting to the idea of the tides of the North Atlantic Ocean being simply derivative from the Great Southern Ocean, does not appear to have thought of the tide through the longest expanse of water on the globe running eastwards against the course of the sun and moon; but he so far accepted the prevailing theory as to suppose the tide-waves to follow the course of the sun and moon westwards through that ocean; whereas, according to the theory suggested in this volume, though the pivot of the tide maintains its position in relation to the force which raises it (or, rather, would maintain that position if the ocean surrounded the globe completely), the tide has, in relation to the surface of the earth, a motion eastwards in the temperate zones, and westwards in the equatorial regions.

Besides the foregoing, the theory in Chapter X. accords with and explains the fact of the spring-tides occurring a day or two after new and full moon, and the neap-tides a day or two after the moon's quarters. For it is only some time (approximately stated as two days) after the moon has been in conjunction or opposition that the lunar and solar tides are in conjunction; and the same time after being in quadrature, the lunar and solar tides are in complete opposition. It is because the apparent course of the earth round the moon is in the opposite direction to that of its course round the sun (the real course of the moon round the earth being in the same direction as that of the earth round the sun), that the conjunction of the tide raised by lunar gravitation with that raised by solar gravitation occurs about the time when those bodies are in opposition, and not when those bodies are in conjunction. And it is because the orbit described by the earth in its course round the moon is smaller than that which it describes in its orbit round the sun that the time at which the tides are in conjunction does not coincide exactly with the time at which the sun and moon are in opposition.

Note.—Independently of the configuration of the oceans, the meeting of the equatorial tide with those converging towards it from the polar regions, together with the convergence of the meridians, may give the tides a general tendency to a greater rise and fall in the temperate zones than elsewhere.

BOOK VII.

REFUTATION OF OBJECTIONS TO THE FOREGOING VIEWS.

CHAPTER XV.

REFUTATION OF OBJECTIONS, ON *A PRIORI* GROUNDS, AGAINST THE POSSIBILITY OF THE EXISTENCE OF THE ACTION OF VIS-INERTIÆ IN THE OCEAN OR ATMOSPHERE.

Dr. Charles Hutton appears to have been among those who rejected the idea of the winds being an adequate caüse to account for the currents known to exist in the ocean; for he speaks of the 'natural and general currents of the sea' as 'arising from the diurnal rotation of the earth on its axis, or the tides,' &c. [1]

But, though appearing to regard the axial rotation of the earth as the cause of oceanic currents, Dr. Hutton discards its action in the atmosphere; though he gives no reason to show why, if the arguments used to disprove the existence of the action of vis-inertiæ in the atmosphere be valid, they are not to be regarded as equally valid if applied to the ocean.

In speaking of the winds, Dr. Hutton mentions that Descartes, Rohault, and others, considered the diurnal rotation of the earth to be the cause of these

[1] *A Philosophical and Mathematical Dictionary.* By Charles Hutton, LL D. London, 1815. Article, Current.

aërial currents; and says that against this hypothesis it is urged that—'the air being kept close to the earth by the principle of gravity, would in time acquire the same degree of velocity that the earth's surface moves with, as well in respect of the diurnal rotation as of the annual revolution about the sun, which is about 60 times swifter.'[1]

Now, in the first place, hypothetically, let every word of this be unreservedly admitted,—and even more—let it not only be said that the air would *in time* acquire the same degree of velocity that the earth's surface moves with, because it might then be argued that the air has not yet had *sufficient time* to acquire that degree of velocity, and that therefore vis-inertiæ, not being yet overcome by gravitation, still causes movements of the air and water—therefore let it, I say, in the first place be asserted and admitted that the air and water have, and must have, the same degree of velocity that the earth's surface moves with, both in respect to the diurnal rotation and orbital motion, and that the laws of gravitation will not admit of its being otherwise.

If taken literally, even admitted in this more absolute manner, that which is offered as an objection to the possibility of currents being caused by the motion of the earth, instead of being a real objection, would, as far as the axial rotation of the earth is

[1] *A Philosophical and Mathematical Dictionary.* By Charles Hutton, LL.D. London, 1815. Article, Wind.

concerned, absolutely necessitate the formation of currents westwards, both in the ocean and the atmosphere—those of the atmosphere having the greater velocity ; because, since the circles of rotation in the ocean, and still more in the atmosphere, are greater than those of the surface on which they rest, therefore, unless the velocity of the motion of the ocean and the air be greater than that of the surface on which they rest, they must lag behind, forming currents westwards ; therefore, if in the motion of axial rotation the air has the same velocity that the earth's surface moves with, it must then have a relative motion westwards over the surface of the earth.

And, as far as the orbital motion of the earth is concerned, that which is offered as an objection is not logically an objection at all ; because, since in the orbital motion of the earth all particles of the solid surface of the earth move in equal ellipses with equal velocities, therefore, the atmosphere, without changing the relative positions of its particles as regards each other, might, by its particles moving in concentric ellipses, keep pace with the earth, and at the same time have a relative motion over the surface of the earth in lines parallel with the plane of the ecliptic ; and at a velocity amounting in the plane of the ecliptic to more than sixty miles a day.

It thus appears that, if taken literally, that which has been offered as an objection to the possibility of any current-creating action resulting from the motions

of the earth—does, in fact, necessitate a current-creating action in the plane of the equator as far as the axial rotation of the earth is concerned : and that it admits of a current-creating action in the plane of the ecliptic, as far as the orbital motion of the earth is concerned, at a velocity of more than sixty miles a day.

I do not, however, by any means suppose that I have replied completely to the sense in which the objection is intended to be understood. The objection appears to be twofold.

One of the objections intended appears to be, that since the velocity of the earth's orbital motion is more than sixty times greater than that of its axial rotation, therefore, if the atmospheric currents said to be caused by axial rotation really were so, there ought then to be far more manifest effects resulting from orbital motion. But in reply to this I have shown, in Chapter III., that the current-creating action of vis-inertiæ depends on the differences in the force of its action in different parts of the ocean (or atmosphere), and that, in consequence of this, the current-creating action of axial rotation is far greater than that of orbital motion.

And if, instead of the literal sense of the objections above refuted, it be asserted that the ocean and atmosphere are held in their positions, *in relation to that part of the surface of the earth on which they rest*, by gravitation, and that no action of vis-inertiæ can

even in the least degree modify or affect those positions,—let this, then, also be admitted: and even then, supposing all the particles of which either the ocean or the atmosphere is composed to be of the same specific gravity, it is then clearly of no importance, as far as the laws of gravitation are concerned, how those particles arrange themselves in relation to each other within the bounds in which gravitation tends to hold them. The particles may indeed, as far as gravitation is concerned, arrange themselves in any conceivable manner: and if any causes whatever tend to set the particles in motion, all that the laws of gravitation can require is, that as particles vacate any position they must immediately be replaced by other particles. It is of no importance, as far as gravitation is concerned, what the forces may be which cause the particles to exchange positions. If anything cause a difference in the relative specific gravity of the particles, then gravitation will itself cause them to exchange positions. Or, if any force whatever be brought into play, acting with greater force in one direction, or in one place, than in another, among particles of equal specific gravity, then, since, as far as gravitation is concerned, the particles may exchange positions in any conceivable manner, and since a cause exists to move some of the particles, a motion must be effected. When force, unopposed by equal force, urges particles from any position, they leave it, and, simultaneously with their motion from

the given position, gravitation draws other particles into the position vacated.

According to the foregoing considerations—first, as regards the orbital motion of the earth, or any onward motion of the earth :—as the earth moves in any given direction, then, wherever least obstruction exists to prevent the progress of the water in the opposite direction, there vis-inertiæ acts more freely than elsewhere : its existence as a cause necessitates an effect, and, as any particles are set in motion by vis-inertiæ, gravitation draws other particles into the positions vacated, to be in their turn expelled and replaced—and so on, as long as the motion which causes the preponderating action of vis-inertiæ to occupy any given position lasts. And thus a circulation of the ocean is effected by a current running through the deep and central parts of the ocean in the opposite direction to that of the earth's onward motion, and returning to the source of action by counter-currents along the shores ; and this without the position of the ocean, as a whole, being in any way affected, as it is carried along with the motion of the earth, firmly held to the earth's surface by the laws of gravitation.

Then also, as regards the axial rotation of the earth eastwards—in which, as already explained, there is not only the current-creating action westwards through the deep and central parts of the ocean, but also that great inequality in the velocity of the motion in polar

and equatorial regions, in consequence of which the current-creating action resulting from axial rotation preponderates over that resulting from any motion by which all parts of the earth's surface are moved with the same velocity :—in this, as in the preceding case, a circulation is effected by currents running with the action of vis-inertiæ in the regions of greatest force, and counter-currents returning to the source of action through the regions of lesser force: and this without the position of the ocean, as a whole, being in any manner affected, as it is carried along with the motion of the earth, firmly held to the earth's surface by the laws of gravitation, which, as we have seen, simply grasp the ocean as a whole, and do not tend to obstruct the action of any forces, of whatsoever nature they may be, which may tend to cause a change in the relative positions of particles of the same specific gravity.

It has also been objected against the action of vis-inertiæ that it must tend to retard, and therefore in the course of time to annihilate, the motion of the earth.

But, in the first place, without a knowledge of the nature or mode of action of the forces which cause the various movements of the earth, it is not possible for us to know whether the action of vis-inertiæ would or would not retard those motions. A cannon-ball is retarded in its course because the retarding action of

the atmosphere is continuous, whereas the propelling force is not: but a rocket is not retarded in its course (as long as it lasts) because the propelling force, as well as the retarding action, is continuous; and the velocity throughout is therefore proportioned to the amount by which the propelling force exceeds the retarding action. If the motion of the earth be of the latter nature, then, even admitting the retarding action of vis-inertiæ, the velocity of the motion, being evenly proportioned to the resistance, would be as lasting as the propelling force, the endurance of which need not necessarily be considered to be limited, as in the case of the rocket. And even if the nature of the forces which move the earth be shown to be such that the action of vis-inertiæ in the ocean and atmosphere must necessarily retard and gradually annihilate the earth's motions: this would not disprove the existence of the action of vis-inertiæ, unless it be also shown that the motion of the earth will never be retarded.[1] The existence or non-existence of the action of vis-inertiæ in the ocean is a question to be decided by practical investigation, and not by theoretical opinion concerning its reaction on the motions which produce it.

The question as to whether the action of vis-

[1] A Paper on the Retardation of the Earth's Rotation, read before the Royal Astronomical Society by the late Professor Adams, since the first publication of the above, has practically annulled the objection.

inertiæ does or does not exist in the ocean is, therefore, not affected at all by such considerations as those which have been urged against it. The real questions at issue are: what is the nature of the forces which move the earth, and what the manner in which they act? And, therefore, in the absence of definite knowledge on these points, the question as to whether vis-inertiæ acts on the ocean and atmosphere or not must be decided by observing what the actual movements of those fluids are, and whether movements in accordance with what may be shown to be the natural action of vis-inertiæ, and which cannot be regarded as effects of any other reasonable cause, do or do not exist in those fluids.

The displacement of the ocean from the poles towards the equator, alluded to in the first book, sufficiently indicates that vis-inertiæ does act on the ocean; and the arguments contained in the five subsequent books show that it tends to cause a system of circulation closely according with the most marked and constant features of that which actually exists in the ocean.[1]

[1] Throughout *The New Principles of Natural Philosophy* further refutations of objections are given on points not discussed in this volume.

CHAPTER XVI.

REFUTATION OF AN ARGUMENT SUGGESTING A SUSPENSION OF THE ACTION OF GRAVITATION.

I have heard it asserted that the spinning of a top shows that its motion causes the action of gravitation on it to be suspended whilst that motion lasts. But this is an unnecessary assumption. I say that the direct action of gravitation tending to make it fall is exactly the same as if it were at rest, and that astral gravitation is the force which keeps the top from falling. For as the relative number of the orbital revolutions of the planets in a given time increases as the square root of the sun's revolving force, it may, I think, be admitted that the resistance of astral gravitation increases as the square of the velocity of the motion which it resists. As far as the present argument is concerned, it is, however, immaterial whether the force of astral gravitation increases as the square or as the cube of the velocity or in any other ratio. Let us suppose it to increase as the square.

Then let the falling motion be any amount, say 4 ; and the mean rotating motion of one half of the top in any direction 8.

Then the actual motion of one half is 10, and that of the other half 6 in the opposite direction.

Therefore, when not rotating, the force with which the top resists the earth's gravitation is 4 squared, and with the above motion of rotation it becomes 10 squared less 6 squared; so that that rotation increases its resistance four times, and a faster rotation would increase it still further.[1]

[1] The above subject is further explained in Chapter VIII. of *The New Principles of Natural Philosophy*. A complete demonstration is also given in Chap. XXI., Proposition XXVI., which has been added to the present edition of this work for the purpose.

BOOK VIII.

REFUTATION OF ACCEPTED THEORIES BY WHICH EXPLANATIONS OF THE MOVEMENTS OF THE OCEAN AND ATMOSPHERE HAVE BEEN ATTEMPTED.

CHAPTER XVII.

ON THE RELATIVE ACTION OF THE TIDES, THE WINDS, SPECIFIC GRAVITY, AND VIS-INERTIÆ.

Book II. demonstrates theoretically the action of vis-inertiæ in the ocean, and Book V. shows that movements according with those theoretical deductions are apparent. We will now proceed to consider whether the currents which exist in the ocean may not more naturally be ascribed to the action of vis-inertiæ than to that of the winds, evaporation, or any other current-creating forces.

The action of the winds in causing currents, by driving the surface-water before them, has been described by Major Rennell; and that of evaporation, which, by causing differences of specific gravity, tends to create currents to restore the equilibrium of the ocean, has been advocated by Captain Maury.

Major Rennell, in his work on the Currents of the Atlantic, says:—'The tides do not occasion an absolute removal of water from one place to another, except very near the coasts; and even that motion is very circumscribed. 'The winds (with very few exceptions) are to be regarded as the prime movers of

the currents of the ocean. . . . Operating incessantly on the surface of the ocean,' the wind 'causes, in the first instance, a gentle, but general, motion of the fluid to leeward (as is proved by ships being always found to leeward of their reckonings in the Trade Winds); and the water so put in motion forms, by accumulation, streams of current.'[1]

Here, without argument, the author quoted assumes the very basis of the question at issue to be proved. For, though the motion of the ships to leeward when sailing in the Trade Winds be accepted as a proof that the water in which they sail moves to leeward, it is clearly no proof that the motion of the water is caused by the winds: but as far as this motion to leeward is concerned, the atmospheric and the oceanic currents may both be effects resulting from the action of the same cause, *vis-inertiæ*; the pressure of the superincumbent atmosphere, in more rapid motion than the water, tending only, to some extent, to increase the natural motion of the latter in those localities where, as is generally the case in the region of the Trade Winds, the action of vis-inertiæ is westwards in both fluids. If all the oceanic motion westwards under the Trade Winds be proved to be caused by those winds, as Major Rennell assumes it to be, we then certainly have force sufficient to account for the ocean currents which exist, without seeking for other causes; but

[1] In the work mentioned on p. 129.

this, as I have above stated, is the very point at issue.

Captain Maury, whose experience in this matter, both practical and theoretical, is unrivalled, clearly recognises that the winds indisputably do tend to cause currents; but considers that, in respect to other current-creating forces, their action is comparatively trivial, and altogether insufficient to account for the currents which actually exist in the ocean.

Sir John Herschel is surprised that Captain Maury can see 'any possible ground for doubting that the Gulf Stream owes its origin *entirely* to the Trade Winds': and considers that 'if there were no atmosphere there would be no Gulf Stream, or any other considerable oceanic current (as distinguished from a mere surface drift) whatever.'[1] In reply to this alleged supremacy of the winds among current-creating forces, Captain Maury says:—'We know of instances in which waters have been accumulated on one side of a lake, or in one end of a canal, at the expense of the other. The pressure of the Trade Winds may *assist* to give the Gulf Stream its initial velocity, but are they themselves adequate to such an effect? Examination shows that they are not. With the view of ascertaining the average number of days during the year that the NE. Trade Winds

[1] *Encyclopædia Britannica*: Article, PHYSICAL GEOGRAPHY, sec. 57.

of the Atlantic operate upon the currents between 25° N. and the equator, log-books containing no less than 380,284 observations on the force and direction of the wind in that ocean were examined. The data thus afforded were carefully compared and discussed. The results show that within those latitudes, and on the average, the wind from the NE. quadrant is in excess of the winds from the SW. only 111 days out of the 365. During the rest of the year the SW. counteract the effect of the NE. winds upon the currents. Now can the NE. trades, by blowing for less than one-third of the time, cause the Gulf Stream to run all the time, and without varying its velocity, either to their force or their prevalence?' [1]

For these and many other reasons of the same nature, given at length in his work on the Physical Geography of the Sea, Captain Maury rejects the theory which makes the wind the prime mover of the oceanic currents, and considers that—'If we except the tides, and the partial currents of the sea, such as those that may be created by the wind, we may lay it down as a rule that all the currents of the ocean owe their origin to difference of specific gravity between sea-water at one place and sea-water at another; for wherever there is such a difference,

[1] *Physical Geography of the Sea*, by M. F. Maury, LL.D. U.S.N. (New York, 1861), sec. 78. See also the extract from Rennell given on page 129 of this volume, regarding the current alluded to as assisting vessels in their progress northwards against the North-East Trade Wind.

whether it be owing to difference of temperature or to difference of saltness, &c., it is a difference that disturbs equilibrium, and currents are the consequence.'[1]

Though Sir John Herschel argues that the Gulf Stream is caused by the combined action of the NE. and the SE. Trade Winds, and in the extract on the opposite page Captain Maury argues that it is not caused by the NE. Trade Wind, the latter argument is, nevertheless, applicable against the theory which makes (as Sir John Herschel does) the winds in general the principal cause of ocean currents. A general accordance of the movements of the atmosphere and ocean—such as an average motion westwards in the equatorial regions and eastwards in the temperate zones—would naturally result from their being effects of the same cause, and must not be regarded as a proof that they are related as cause and effect. I cannot pretend to do justice to the manner in which the theories of the winds and specific gravity are enforced in the interesting works in which they are respectively maintained. I quote, however, once more from the same article by Sir John Herschel, to show the nature of his objections to the theory which makes differences of specific gravity the principal cause of the currents which exist in the ocean. Allowing that 'Sea-water, by evaporation, acquires additional saltness and density,

[1] Sec. 406 of the work just quoted.

and by dilution with rain, the reverse qualities,' he admits that 'in this fact we have a *vera causa*, though a very feeble one, for the production of an indraught on both sides *towards the lines of maximum evaporation and minimum precipitation*:'[1] but argues that its action is insufficient to cause the currents which exist, and, that it would not tend to give them the direction which they actually have. And, as regards the direct action of the sun's rays, Sir John Herschel says: 'The *surface* of the ocean becomes *most* heated, and the heated water will, therefore, neither directly tend to *ascend* (which it could not do without leaving the sea) nor to *descend*, which it cannot do, being rendered buoyant, nor to move laterally, no lateral impulse being given, and which it could only do by reason of a general declivity of surface—the diluted portion occupying a higher level:' and argues to show that this may be dismissed 'as a cause capable of creating only a very trifling surface drift, and not worth considering, even were it in the proper direction to form, by concentration, a current from east to west; *which it would not be, but the very reverse*.'[2]

[1] Sec. 59.

[2] Sec. 57. I do not profess to endorse all the details of Herschel's argument in the above quotations, but only the correctness of the opinion based upon them, which, since the text above was published in 1868, has been corroborated in a very decided manner by the extract from Sir Wyville Thompson given on page 5 of this volume.

This last remark refers to the fact of the water in the west of the equatorial regions, in each ocean, being warmer than in the east; so that, if the expansion of the water by heat caused an overflow, the stream caused by that overflow would run from west to east; whereas the general course of the water in the equatorial regions is from east to west. It may here also be remarked, in connection with one of the quotations above, that, the heating action of the sun's rays is, by Sir John Herschel himself, admitted to tend to cause the surface-water of the ocean to ascend (causing it to leave the sea in the form of vapour); and, thus, to tend to cause an indraught towards the places of maximum evaporation.[1] The effects resulting from this action are, in fact, discussed in the preceding quotation made from Sir John Herschel.[2]

[1] The places of maximum evaporation being the equatorial regions, the surface indraught would be to those regions; and the 'additional density acquired by evaporation,' as stated in the first of the above extracts from Herschel, would obviously, as indicated in the text above, have a tendency to neutralise the buoyancy suggested in the second extract, and therefore to cause the water to sink in those regions. This action has been elaborately discussed by Mr. Croll. *Climate and Time*: by James Croll, London, 1875.

[2] The conflicting action of the 'additional density acquired by evaporation' and the 'buoyancy acquired by being heated' are indicated in the text above, which stands as first published in Chapter IV. of the *Treatise on Vis-Inertiæ,* and makes it evident that I did not desire to endorse the details of the arguments used by Sir John Herschel.

Besides the objections urged by Sir John Herschel against the theory which makes differences in specific gravity the prime cause of the currents of the ocean, it must be observed that, if differences in specific gravity, resulting from the difference of temperature and other conditions in polar and equatorial regions, were the principal cause of ocean currents—in consequence of the tendency of the heated and cold water to exchange positions in order to re-establish their equilibrium in specific gravity—then, the heated water flowing from the equator would be under that influence of change of latitude which tends to carry it eastwards, and the cold water from the polar regions would be under that influence of change of latitude which tends to carry it westwards; so that, therefore, the warm water would naturally flow from the equator on the east side of the ocean, and the cold water as naturally flow to the equator on the west side of the ocean; whereas in fact, with the existing currents of the ocean, the very reverse is the case; the cold water is brought to the equator partly by currents running towards the equator on the eastern side of each ocean, and partly by under-currents rising to the surface chiefly in the eastern parts of the ocean; then, it flows westwards through the equatorial regions, and flows from the equator on the west of the ocean, as warm currents; having been heated during its course through the equatorial regions.

This actual course of the currents is in accordance

with the natural action of vis-inertiæ as described in Book II., according to which the water flows west in the equatorial regions ; because, the westward pressure in those regions is the greatest of all current-creating forces : also, the water carried west in the zone of greatest force must return east through the zones of lesser force in higher latitudes ; and, therefore, flows from the equator on the west side of each ocean, and returns to the equator on the east : and, the under-currents which convey cold water to the equator, tend to the eastern side of the ocean ; because, their natural tendency westwards must yield to the greater force of the westward tendency of the upper strata wherever the latter can draw no supply directly from the east. The current which flows west in the equatorial regions draws its supply from higher latitudes, because in those latitudes the force of westward pressure is less ; and it draws this supply chiefly through under-currents, because the westward pressure at the bottom of the ocean is less than at the surface.

Doubtless, if no more powerful agencies were in play, then, the disturbed equilibrium resulting from differences of temperature and other conditions in polar and equatorial regions, would cause an intermixing of the waters of the ocean, by means of a system of currents causing a constant interchange of equatorial and polar waters. But, we have to consider how *the system* of oceanic circulation which

actually exists is caused, rather than how *a system* of circulation might be caused in the absence of any more powerful cause. And, if the actual system of oceanic circulation be in accordance with the theoretical action of vis-inertiæ, it must then be admitted that this force is the great prime cause of the ocean currents by which a constant interchange of equatorial and polar waters is effected; so that, by its action, all portions of the waters of the ocean are in their turn alternately exposed to the heat of equatorial and the cold of polar regions without the action of the agencies so interestingly described by Captain Maury, tending to cause differences of specific gravity, being brought into play. Regarding the action of these agencies and that of the winds as comparatively trivial forces, the theoretical action of vis-inertiæ described in Book II. serves to discover and to explain the actual course of the currents by which the circulation of the ocean is effected.

Sir John Herschel is surprised how Captain Maury can doubt that the winds are the great prime cause of ocean currents; and, indeed, theoretically considered, it appears plausible enough to assume that the winds must tend, to some extent, to cause a system of currents, by driving the surface-water before them; which, wherever it accumulates against obstructions, must tend to run off in streams. But, practically considered—that is to say, considering

what are the actual winds which blow, and what the actual currents of the ocean—it appears to me incomprehensible how anyone who studies these systems of aërial and oceanic circulation can reconcile them as cause and effect. It appears to me surprising, how, considering the enormous volume and weight of water borne along in the oceanic currents, anyone can help doubting the power of the comparatively light atmosphere to keep such a mass in motion, even if it were shown that the *course* of the oceanic currents corresponded with that which would naturally result from the action of the winds which exist. But, when it is found that the winds tend to a great extent to neutralise each other, and that, even in the region of the Trade Winds, where the power of the winds is greatest, ocean-currents, even on the surface of the ocean, run across and against those winds, whilst in the lower strata immense under-currents run their course regardless of the winds which blow above ; it then seems surprising how anyone can consider that the position and direction of the ocean currents which exist are in accordance with the current-creating action of the winds, even if it be assumed that the latter are sufficiently powerful to control the vast volume of water which is carried along in those currents.

Major Rennell himself appears to have had less confidence in the power of the winds to cause the existing circulation of the ocean than some who

advocate his theory at present. And many other eminent authorities, besides Captain Maury, have doubted the sufficiency of the winds as a cause for the existing oceanic circulation. Mr. Findlay says: 'It will be seen that throughout the breadth of this ocean the set of the stream is not to SW. or NW., as might be expected from the direction of the Trade Winds, which may be taken as the prime mover of these mighty drifts, but *westward*:' and then adds: 'This fact would seem to indicate that the rotation of the earth on its axis has more to do with its motion than has usually been attributed to it.'[1] From this view, which has suggested itself to many others practically acquainted with the actual movements of the ocean and atmosphere, Sir Charles Lyell differs; and says, after mentioning 'the wind, the tides, evaporation, the influx of rivers, and the expansion and contraction of water by heat and cold,' as causes of currents—'But there is another cause, the rotation of the earth on its axis, which can only come into play when the waters have already been set in motion by some one or all of the forces above enumerated, and when the direction of the current so raised happens to be from south to north, or from north to south.'[2] Sir Charles Lyell does not say why the action of the axial rotation of the earth can

[1] P. 299 of the work mentioned on p. 129.

[2] *Principles of Geology*, by Sir Charles Lyell, Bart., M.A., F.R.S. (London, 1867), p. 500.

only come into play when the waters have already been set in motion by other causes ;[1] and, indeed, though the influence of the axial rotation of the earth here referred to accelerates the motion of currents *caused* by other forces, and determines their direction, or *controls* them in their course, it is not itself, strictly speaking, a *cause* of ocean currents at all. Apart, however, from the question as to whether the term *cause* has been correctly applied in this instance, it is surprising how anyone admitting the action of this influence of the axial rotation of the earth—which, indeed, cannot reasonably be denied,—can, nevertheless, at the same time, continue to enforce Major Rennell's theories regarding the causes of ocean currents. Major Rennell had no idea of the existence in the ocean of this influence of the earth's axial rotation which Sir Charles Lyell admits. It has only recently been pointed out by Captain Maury, and is, in fact, incompatible with Major Rennell's theories ; for we have seen, a few pages back, that, if the waters of the ocean were set in motion from the equator to the poles and from the poles to the equator otherwise than by the action of vis-inertiæ, then, that influence of the axial rotation of the earth which Sir Charles Lyell admits would, as it tends eastwards from the equator and westwards to the

[1] The reason for Sir Charles Lyell's opinion is, however, that which I have explained in Chapter I. of this volume, it being, of course, a consequence of his acceptance of the 'Laws of Motion.'

equator, carry the warm water from the equator on the east side of each ocean, and the cold water to the equator on the west side of each ocean, and consequently eastwards through the equatorial regions; all three of which conditions are exactly the reverse of what is known to be the actual circulation of the ocean. The idea of the Trade Winds being considered a sufficient cause to account for this complete reversal of the course which the currents would naturally take under that influence of the axial rotation of the earth which Sir Charles Lyell admits is one which I do not suppose anyone will seriously maintain: and, indeed, I do not see how it can be accounted for otherwise than by admitting the action of vis-inertiæ; in which case, change of latitude being an attribute of the westward pressure which results from axial rotation, and, that influence of axial rotation admitted by Sir Charles Lyell being an attribute of change of latitude,—then, the action of the latter cannot annihilate that of the force of which it is an attribute; but, a sufficiency of force must be created by the direct action of westward pressure, setting the water in motion westwards in the regions of greatest force, to keep the currents in motion in whatever course the attributes of westward pressure may subsequently tend to give them.

Major Rennell, as quoted on page 179, says that—'The tides do not occasion an absolute removal of water from one place to another, except very near

the coasts;' but I think that the arguments in Book IV. show that, though in an ocean completely covering the globe the tides would not cause any current, nevertheless the breaking-up of them by the coast-lines may necessitate the formation of currents following the general course of the tide-waves, and, therefore, revolving in each ocean, westwards in the equatorial regions and eastwards in each of the temperate zones.

But the question whether the breaking-up of the tides by the coast-lines does or does not lead to the formation of currents through the central parts of the ocean may perhaps be more easily determined by a practical investigation, for the purpose of ascertaining whether or not they are alternately accelerated and retarded at intervals corresponding with the successive passages of the moon across any meridian, than by theoretical disquisitions on the subject. A current-creating action of the tides in the manner here indicated may, it seems to me, be much more effective than that of the winds, whose action, to some extent, is certain, whereas that resulting from differences of specific gravity need not necessarily be brought into play at all where more powerful and rapidly acting forces cause a circulation.

BOOK IX.

THE MOVEMENTS AND CONFIGURATION OF THE SURFACE OF THE EARTH.

CHAPTER XVIII.

PRELIMINARY.

In examining the outer crust of the earth, endeavouring to discover signs of movement, and the nature and causes of the movements which take place, suppose that, after traversing the mountains and plains of Europe, you at length set off to look at the most extensive of all mountain ridges, which is that which extends almost from pole to pole along the western coasts of North and South America. You traverse the pampas, where the land is, for the most part, slightly undulated, so that in riding over it the horizon is constantly changing, and the eye is ever on the alert, as objects appear or vanish in the distance. After passing San-Luiz you traverse a series of undulations which give to the country the appearance of a succession of huge ocean rollers pressing forward in parallel lines towards the mountains. You cannot fail to be struck with the peculiarity of the scene. They are a series of undulations upon a much greater undulation, for the land falls again before reaching the mountains. When yet two hundred miles east of that mountain range, you may catch sight of it as its snow-covered peaks fling

back the rays of the rising sun. You pass through the ruins of the city of Mendoza, which, but five years ago, was destroyed by a comparatively slight movement of the outer crust of the earth. At length you commence to mount the eastern slope of the huge mountain ridge. You may glance eagerly from mountain to mountain, from valley to valley; districts of gravel, districts of sand, districts of earth; stratified masses and unstratified masses: you may glance at all, vainly endeavouring by inductive steps to learn the process of their formation. All appears crude disorder and confusion. As the keen winds rush by, perchance they laugh a derisive laugh; and the vast mountain ranges—rugged, stern, and inhospitable—frown in silent, majestic disdain. Here man is scorned. The rude mountains frown, and the angry winds rage, as if threatening destruction to all who dare to venture here. But man shall triumph yet; for, as you stand upon a narrow ridge which rises like a wall fourteen thousand feet above the sea, and on your right and left snow-covered peaks tower upwards nine or ten thousand feet higher, there, stung by the failure of your efforts by the paths of induction, you boldly rush upon the dizzy heights which are traversed by the dangerous paths of deduction. With a vigorous effort you fling imagination back through time, and let it place you in an age between which and the present countless ages have intervened. You then find that not only the moun-

tains, but the whole continent has fallen away from beneath you, and there now lies below you one vast expanse of water. The water is deep; but below there is a hard stratified ground, beneath which the interior of the earth is in a state of liquid heat, but gradually cooling; and, as it cools, the hardened surface is compelled to bend in graceful curves, in order to suit the decreasing size of the globe. By this bending, the water becomes of unequal depths, deepening in parts as it becomes shallow in other parts. At length, immediately below you, a ridge of dry land appears—this, then, is the birth of the South American continent—it continues gradually to rise, throwing off the water to the east and west; there, then, lies the Pacific, and there the Atlantic Ocean. The bending upwards and downwards, in the same easy graceful curves, continues as long as the surface remains sufficiently pliant; but at length, becoming more hard and brittle, as the strain still continues, it cracks with a tremendous crash, the rent extending north and south, almost from pole to pole. Up to this moment the surface has yielded gradually to the power of gravitation, offering great resistance. But, once broken, this resistance is gone, and gravitation, acting with unchecked power, crushes and grinds the broken edges together with a force scarcely conceivable by the mind of man. Enormous masses of what had once been horizontal strata are now perpendicular, or even reversed. The smashing

and grinding of the broken edges, by the overwhelming lateral pressure caused by gravitation, leaves scarcely a trace of the former stratified order, but leaves mass piled on mass in vast confusion, forming this huge mountain range along the course of the crack. And, more than this: the outer crust of the earth had hitherto been in a great measure self-supporting, its weight resting upon itself laterally in all parts, so that the interior parts of the earth were in the same measure relieved from the weight of its inward pressure. That is, inward pressure had been changing to lateral pressure, in proportion as the hardening surface of the earth offered increased resistance to the power of gravitation. But when the hardening surface of the earth, becoming more brittle, had bent upwards as far as it could without breaking, it at length breaks along the top of the ridge, and, in proportion with the loss of lateral support thus caused, the weight of the adjacent parts of the surface press inwards; and, the inner parts of the earth being in a state of liquid heat, the increased weight pressing upon the fluid part forces the fluid matter upwards through the fissures in the crack; and thus, in some places, mountain ranges of unstratified rock are formed as the fluid hardens on the surface; but here the accumulation of broken masses of stratified matter is so enormous that this part of the range seems to consist of nothing else. The stratified surface to the east of the crack has here

overlapped that to the west. So that on the west, the Pacific Ocean rolls against the disjointed masses that have been piled up about it; whereas on the east, the elevated strata slope away gradually to the Atlantic Ocean. That slope is itself undulated by pressure; but those undulations are probably precedent to the occurrence of the crack which led to the piling up of the Andes; most, if not all, subsequent readjustments of the surface having been arranged by movements along the still unfirmly placed edges of the crack. The sudden movements in this neighbourhood even now cause at times a shock, or earthquake, sufficient to overwhelm cities. In these movements, also, either by direct pressure of the surface downwards, or oftener probably by water or other matter being suddenly brought into contact with intense heat, matter from below the stratified surface is, in a state of liquid heat, forced upwards through openings in the crack; thus forming, as the matter hardens on the surface, those high volcanic peaks which are here so numerous. Or, in other places, the same expansion not having sufficient force to burst through the surface, simply raises it in the form of an evenly rounded hill.

Now, if these observations be not erroneous, we must conclude that granite, and most unstratified rocks, are in general forced to the surface in the same manner as is mud through the fissures between paving-stones; that is, not by the direct pressure of

the granite upwards, but by the pressure of the stratified surface downwards. As long as the stratified surface remains unbroken, it is in a great measure self-supporting, resisting the power of gravitation, to which it gradually is compelled to yield by bending, until at length it breaks. When once the breakage occurs, the adjacent parts, no longer offering the previous resistance to gravitation, are drawn inwards, pressing upon the liquid granite below, and forcing it outwards through the fissure. Now, if we suppose two great breakages to have been caused by the force of lateral pressure, the one corresponding with the course of the Rocky Mountains, the other with that of the Sierra Nevada of California, it is obvious that the intervening portion of the earth's surface, having up to the time of the breakage been in a great measure supported laterally, will, after its occurrence, exert an increased pressure inwards proportionate to the loss of lateral support; and this inward pressure, acting upon matter in a fluid or semi-fluid state, will, to a greater or lesser extent, force that fluid matter upwards, through the breakages; so that the unstratified rock would appear in ridges along the course of each breakage. Looking at the Yosemite valley in the Sierra Nevada, a superficial glance makes it appear probable that, after a granite district having been formed here in the manner just suggested, the bending of the surface caused by

lateral pressure has continued, whilst the granite was becoming cool and hard on the surface, and that as soon as its surface became too hard and brittle to bend further, it cracked along the top of a bending ridge, the upper edges parting asunder, and leaving a deep wedge-shaped gorge. The débris from the sides and part adjacent to the crack has filled up the lower part of it, and formed the present bottom of the valley.

There are some trees which, when young, are covered with a smooth thin bark; but as the tree grows the pressure from within bursts the first layer, disclosing through the crack a new layer, proportioned to the increased growth of the tree. Thus layer after layer forms and bursts; and, as the old layers continue to adhere to the tree, ridges are formed which as each successive layer is added get higher, and the hollows between them wider and deeper, until at length the bark of the old trees presents that rough, uneven surface, which at first sight looks so strange. Now, glance at the bark, or outer crust of the earth—it also presents a rough, uneven surface, rising and falling in mountains and valleys. The cause of this unevenness in the surface of the earth, though diametrically opposite, is no less simple, and no more wonderful than the cause of the unevenness in the surface of the tree. The latter is an expanding force—the former is a contracting force. As contraction proceeds in the

interior of the earth, the outer shell, not being sufficiently strong to resist the power of gravitation and support itself, must either bend or break, so as to accommodate itself to the reduced circumference which it has to enclose. A glance round the world shows that it has bent all over, and in many places broken. In some parts the bending is only sufficient to form gentle, easy undulations ; in other places, sufficient to form hills and valleys ; and where the surface, after bending as much as its pliancy would admit of, has at length broken, the broken edges, crushing against each other, have piled up mountain ranges of broken strata ; or, in other places, the inward pressure of the stratified surface has forced the liquid matter from below upwards through the crack, forming chains of unstratified mountains.

CHAPTER XIX.

THE ACTION OF VIS-INERTIÆ ON THE SURFACE OF THE EARTH.

It is evident that, if from the oblate spheroidal form of the earth, resulting from axial rotation, we can infer an action of vis-inertiæ in the ocean, such an inference is equally applicable to the outer crust of the earth. So that, according to this, the whole surface of the earth, and all upon it, must tend to lag, while some revolving force within is dragging it round eastwards.

And can any natural phenomena be adduced in refutation of this view? It may, with exquisite logic, be shown to be at variance with assertions which have for some generations been taught in schools and colleges as laws of motion; but it cannot, I think, be shown to be at variance with absolute fact; and I will now briefly consider what movements and configuration of the outer crust of the earth should result from an action of vis-inertiæ on it similar to that described as acting in the ocean, in order to ascertain whether the actual configuration is such as to admit of its having resulted from the action of that force.

For the sake of illustration, let us suppose the earth in the condition described in the foregoing chapter—namely, with an outer covering of air; beneath that air an unbroken expanse of water; beneath the water a hardening, but still more or less pliant, surface of land; and beneath the land a fluid, incandescent, and gradually contracting mass, homogeneous with the materials whose solidification has formed the outer crust or land.

Under the sole action of its own force of gravitation that globe would naturally tend to preserve its form as a perfect sphere. But by the motion of rotation round its axis a centrifugal force is created, acting from the axis towards those parts of the surface which, being most remote from the axis, rotate with the greatest velocity. On the surface of the globe this force acts from the poles of the axis towards the equator. And, supposing the land or outer crust of the globe to be sufficiently pliant, then the liquid mass within it would bulge it out all round the equator and draw it inwards at each of the poles; thereby causing its equatorial to be greater than its axial diameter. The action of this force would not tend to cause any difference between the hemispheres lying on either side of the equator; but, as far as its action is concerned, those hemispheres would be equal and their configuration similar.

The tendency to contraction, as described in the foregoing chapter, induces lateral pressure through-

out the outer crust of the earth; and if that outer crust have not sufficient strength to resist the action of gravitation, it must, if sufficiently pliant, have a tendency to undulate all over; or, if not sufficiently pliant to undulate, its tendency must then be to shiver to fragments. Let us consider in what manner this tendency to undulate or to fracture can be affected by the action of vis-inertiæ.

We have seen that the action of vis-inertiæ resulting from axial rotation, and that resulting from orbital motion, both act westwards in any given part of the surface of the earth when that part of the surface is turned from the sun, but as soon as that part of the surface reaches the point of sunrise, then the conjoint action of those forces ceases; the orbital force turns eastwards, and acts in opposition to the force resulting from axial rotation. Thus, then, the alternate conjunction and opposition of these two separate actions of vis-inertiæ would control the undulating action of lateral pressure, and cause those undulations to take the form of a series of ocean waves sweeping westwards; for the action westwards is the strongest, and it receives a check during each rotation of the earth. These, then, appear to be the forces which have determined the peculiarities of conformation, which have been so clearly pointed out by the late Rear-Admiral Fitzroy in the following passage, which I extract from the 'Weather Book.' On page 121 of that work Admiral Fitzroy draws

attention 'to a very remarkable geologic conformation, common to a great part of our world approachable by sea, though not so much to the far interior of extensive continents : namely, gradual slope up from east towards west, and comparatively precipitous steeps, from summits, westward. Norway, Europe generally, Africa, with its outlying islands, both Americas, the Galapagos, the (elevated) Polynesian islands, the ranges of Australia, China, and Asiatic sea-coasts generally, when viewed extensively in profile from south to north, have the wedge-like outline that is familiar to Englishmen in the Bill of Portland. To the physical philosopher and the geologist we must turn for reasoning on this striking peculiarity—one that the writer has often noticed and considered with extreme interest. His attention was first drawn to it by seeing the Galapagos group, from a distance, appearing like several "Bills of Portland," all exactly similar in their profile outlines when many miles distant. Since that time (1836), many opportunities have occurred for inquiries and careful comparisons, of which the result is a belief that (excepting those greater east and west ranges of mountains embodied within continents, or continental islands, such as Australia and Borneo), the general average direction of ranges or chains of mountains is nearly meridional, and their section approaches that of a wedge (pointing eastward).

'This wedge-like shape is common to every little

sand-ridge, every shifting shingle bank formed along shore by wave or tidal action. It is also that of sand-ridges on a plain, drifted by wind alone, and it is the form of snow-drifts—the point of the wedge being towards the source of action. Whether water, or wind, or both, acting *continuously*, have been agents in these conformations; whether, in contracting or expanding, the earth's surface or crust has had a tendency to scale-like fracturing, must be left to the consideration of competent judges.'

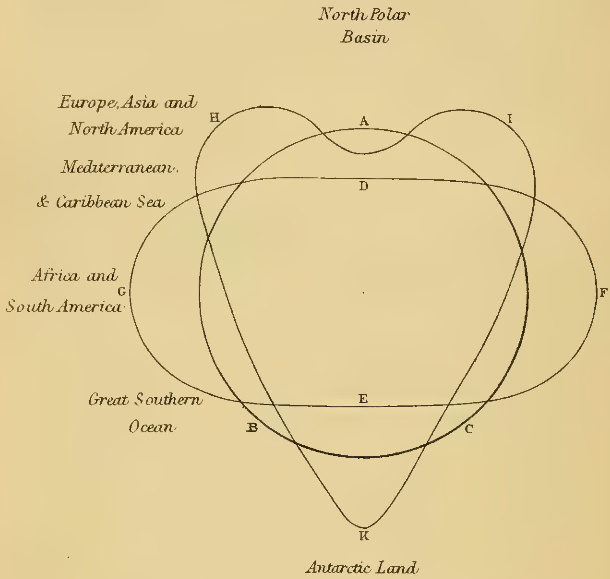
These conformations, observed by Admiral Fitzroy, appear clearly to coincide with such as might naturally be expected to result from the alternate conjunction and opposition of the two actions of vis-inertiæ in combination with the undulating tendency of lateral pressure.

Besides the motions of axial rotation and orbital revolution, whose effects we have just considered, let us suppose the earth to have an onward motion southwards, since the evidence deduced from the course of the currents of the ocean has indicated a motion of the earth in the direction of the South Pole or thereabouts.

And since, according to the theory just sketched, the motion of the earth results from attraction, it seems natural to expect that the movements of the magnetic-needle may be an effect of the action of the force which is carrying the earth onwards in that course. And, if so, we may then infer that the

tendency of magnetism is to turn the positive end—that is, what is commonly called the north pole of the needle—in the direction of the earth's motion; that is to say, in the direction of the South Pole, or thereabouts. And, as in the ocean, lines of lesser force are overwhelmed by lines of greater force, so that currents are caused to run along the lines of lesser force in the opposite direction to that in which the force which impels them acts; so also must the northward direction of the magnetic-needle result from the overwhelming of lines of lesser magnetic force by those of greater force; that is to say, the lines of magnetic force must run through the central parts of the earth from the north to the south magnetic pole, and then spread out over the surface of the earth towards the equator, crossing which, they must converge again towards the north magnetic pole; so that the lines of greatest force, running through the central parts of the earth, overwhelm the lines of lesser force on the surface of the earth; thus causing the needle, when placed in the lines of lesser force, to point in the opposite direction to that in which magnetism acts; and, at the north magnetic pole, being in the line of greatest force, to point down through the central parts of the earth to the South Pole; and, at the south magnetic pole, to point right away into space, marking the point in space towards which the earth may be moving.

Then, by the magnetic action which we have



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described, the surface of the earth should be drawn inwards about the North Pole, bulged outwards about the South Pole, pressed downwards between the South Pole and the equator, and piled upwards between the equator and the North Pole; because the force returning from the South to the North Pole would, in the southern hemisphere, be pressing the surface of the earth from latitudes of lesser into latitudes of greater circumference; whereas, in the northern hemisphere, it would be pressing the surface from latitudes of greater into latitudes of lesser circumference.[1]

The independent action of each one of the forces I have described is illustrated by the curve lines in Plate XVI.: in which the sphere shows the action of

[1] According to Mr. Croll's work, *Climate and Time*, already alluded to, the great Southern Ocean exists in consequence of the southern 'ice-cap' having moved the earth's centre of gravity southwards; whereas, according to the argument above, that ocean exists in consequence of the surface of the earth having collapsed in the temperate regions of the southern, and bulged out in those of the northern hemisphere under the influence of the earth's motion through space.

The latter action is corroborated by the existence of the Arctic Ocean, almost encircled by the lands of the Northern Hemisphere; and by the Antarctic lands surrounded by the ocean of the Southern Hemisphere; whereas, the attraction of the water to the Southern Hemisphere by the 'ice-cap' would have tended to leave the Arctic Regions all dry land, and to submerge the Antarctic Regions as much as the South Temperate Zone. The great height of the mountains in the Antarctic Regions, where in corresponding latitudes in the Arctic Regions no land exists, seems at variance with the idea of the ocean having been drawn southwards by the formation of the 'ice-cap.'

gravitation ; the oblate spheroid the action of centrifugal force, resulting from axial rotation ; and the cardioid the action of magnetic force, resulting from motion through space. And under the combined action of these forces the configuration of the earth would, therefore, be such, that if on the surface of the earth there lay water sufficient to cover one half of the earth's surface—that water lying in each of the depressions, and leaving the protuberances dry land—then the surface of the earth would be divided into the following alternate zones of land and water: namely, land about the South Pole; a vast expanse of water throughout the temperate regions of the southern hemisphere; a zone of dry land in the equatorial regions ; a narrow zone of water north of the equator ; a zone of dry land throughout the temperate regions of the northern hemisphere ; and a district of water about the North Pole.

The land in the temperate zone of the northern hemisphere, and that about the South Pole, would be raised by the action of the magnetic force concomitant with motion through space : and the land in the equatorial zone would be raised by the action of the centrifugal force concomitant with axial rotation. The relative positions of land and water resulting from the action of the forces just described strikingly correspond with the actual relative positions of land and water in each hemisphere, as is shown by the illustration given in Plate XVI. ; excepting

that the zones, instead of being continuous, are intersected by undulations running north and south.

In the north there is the depression which contains the Arctic Ocean, surrounded by the continents of Europe, Asia, and America; then there is the depression of which the Mediterranean and Caribbean Seas, separating Europe and North America from Africa and South America, form a part; and thirdly, there is the greatest hollow, which contains the Southern Ocean, separating the continents just mentioned from the lands of the Antarctic regions.

Though the centrifugal force resulting from axial rotation might be expected in some measure to neutralise the undulating action of lateral pressure acting north and south, so that the greatest apparent effects of undulating force should result from the pressure acting east and west; this would not account for any one of the meridional undulations being greater than any other. But, as far as the forces thus far considered are concerned, all the meridional undulations on our hypothetical globe would be equal and similar. There are, however, on the surface of the earth two meridional undulations immensely greater than all others, the crests of which form respectively the Old and New Worlds; the depressions between them containing respectively the Atlantic and Pacific Oceans.

Such a meridional division of land and water would naturally result from a change of the earth's

axial rotation from any axis to a new axis at right angles to the position of the old axis. And, in fact, if in this sketch I have correctly described the action of the forces brought into play, then it would appear from the actual conformation of the outer crust of the earth that such a change of the axis of rotation as above mentioned has occurred, not once only, but many times. In such case the wave-like conformations observed by Admiral Fitzroy must have been formed since the occurrence of the last change of axis : these comparatively modern undulations intersecting older similar undulations, and obliterating, to a greater or lesser extent, the traces of their original conformation.

Let us consider how such a change of axis as that just mentioned would affect the configuration of the globe which we have been describing. By such a change the position of the poles of the new axis would be in opposite points of the old equator : and the new equator would intersect the old at points ninety degrees from each of those poles. The equatorial diameter between those points would then be greater than that at right angles to it ; for this latter would be the line of the former axis of rotation. And centrifugal force, carrying the water to the equatorial regions, would cause it to accumulate in two great oceans whose central points would be over the poles of the former axis : and those oceans would be separated meridionally by a belt of land lying

along the line of the former equator. Then, supposing the outer crust of the earth to be sufficiently pliant, the configuration which the action of the forces before described would tend to restore would be modified by meridional undulations. For those undulations which, before the change of axis, formed the zones of land and water running parallel to the old equator, would after that change of axis lie meridionally, or at right angles to the new equator.

In this new position, under the action of the forces which caused the former configuration, a portion of the former equatorial regions would be sustained to form the new Antarctic continent, and the opposite part depressed to form the basin of the Arctic Ocean. And also, from the central parts of one of the great oceans, there would gradually be upraised the crest of the undulation which had formed the old Antarctic continent; and about the central parts of the other of the great oceans there would gradually be upraised the crest of the undulation which had encircled the former Arctic Ocean. The undulating tendency of lateral pressure, acted upon by the actions of vis-inertiæ resulting from axial rotation and orbital motion, would then tend to raise a new series of meridional undulations intersecting, at right angles, those previously raised by the action of those same forces.

If a portion of Brazil be supposed to have formed at one time an Antarctic continent, then the

actual configuration of land and water on the surface of the earth presents a striking resemblance with that which would naturally result from the action of the forces just described.

The clear records of glacier action on an enormous scale traced by Professor Agassiz over all parts of Brazil which he visited give support to the idea of the last change of the earth's axis being as above suggested.[1] And it is also interesting to observe that the only part of the present continents which, notwithstanding that change of axis, would have preserved its position relatively with both the poles and the equator, and would in those former times, as well as in the present, have enjoyed a temperate climate, is the very spot which the accepted traditions of the Caucasian race record as being that where our ancestors escaped destruction during such a deluge

[1] The striations and apparent remnants of glacier moraines on the Tijuca Hills and the Organ Mountains near Rio de Janeiro, which, at the time I published *The Elements*, and for eight or nine years previously, I supposed to be traces of glacier action similar to what I had seen among the glaciers of Norway and Switzerland, I afterwards found to be effects of the sliding of a stratum of broken rock over the solid rock of which the mountains are formed. A stratum of very hard and brittle rock seems to have been shivered to fragments, and, the parts adjacent to each crack having decomposed, the whole mass has taken a downward motion over the mountain sides, not only causing striations exactly similar to those caused by glacier action, but also leaving moraines which, though in general appearance similar to glacier moraines, are formed in consequence of the portion of the same stratum, which formerly surrounded them, having moved away more rapidly on steeper declivities. This of

as would naturally result from the suggested change of the earth's axis.[1]

Besides the above change of axis, some previous changes would be requisite in order to account for the absence of land in the central parts of the Pacific, opposite the equatorial regions of Africa.

The investigation of this point offers a problem, intricate and interesting, but unsuited to the purpose of this chapter, which is simply to illustrate the universality of the action of the forces which determine the position and movements of the ocean and atmosphere. And, if the foregoing arguments be not erroneous, then the actual configuration of the earth's crust shows the action of the forces in play in

course does not disprove the supposed glacial period, but merely proves that the surface has undergone more important changes since that period than I and, as it seems to me, Professor Agassiz at one time thought apparent. I, at any rate, supposed the surface of the ground in Brazil to be almost as left after the melting of a heavy covering of ice, but I have found that to have been a mistake, for there have been considerable changes since the existence of any glacial epoch there. Or, at least, causes now in action could very well have produced all the 'striations' and 'moraines' that I have seen there.

[1] 'In those days Noah saw that the earth became inclined.'—*The Book of Enoch*, lxiv. 1.

'The earth labours and is violently shaken.'—*Idem*, 3.

'The fountains of the great deep were broken up.'—*Genesis*, vii. 11.

'And the foundations of the earth became equalised, while other depths were opened; into which the water began to descend, until the dry ground appeared.'—*The Book of Enoch*, lxxxviii. 9 and 10.

the ocean and atmosphere and confirms that southward motion of the earth in the first instance deduced from the observed course of the ocean currents.[1]

[1] A further development of the action of vis-inertiæ on the surface of the earth is given in *The New Principles*, as stated in the footnote to Proposition X., Chapter XXI. of this volume.

BOOK X.

THE ACTION OF VIS-INERTIÆ IN THE HEAVENS.

CHAPTER XX.

PRELIMINARY.

In Book I. a single phenomenon was accepted as sufficient to indicate that a force whose action is a matter of commonplace knowledge, is in play in the ocean in the same manner as that in which its action can be observed in ordinary phenomena.

In Book II. it is shown that the action of that force in the ocean tends to cause the elaborate circulation through the system of ocean currents there described.

In Book III. it has been ascertained that the force which causes the foregoing system of circulation is intrinsically the same as that which causes the well-known phenomena of the tides.

And it has been shown that that force must tend to give both the moon and its tide a relative motion over the surface of the earth by the same action as that which circulates any particle of water in the ocean. And a cursory consideration of the motions of the moon and the planets has shown that they are not at variance with the action of that force.

That analysis has shown that the vis-inertiæ of

matter is the source of gravitation, through the action of which the apparent motion of every star must affect the ocean in the same manner as the corresponding motions of the sun and moon.

Just as the lunar tide follows the apparent motion of the moon, so also a similar action of the gravitation of every star draws the water in the direction of its apparent motion ; but as the stars are distributed all round the earth, the combined action of their innumerable tidal forces causes the equable system of circulation on which the lunar and solar tides are excrescences, on account of the irregularity of the action of these latter bodies on different meridians not being balanced by the action of bodies at the same distance on other meridians.

Thus the ocean moves in concert with every motion of every star, just as it moves with the movements of the sun and moon, so that every movement in the universe is, as it were, reflected by a corresponding movement in the ocean.

The object of this Book will be to endeavour to trace in the heavens the action of the force which forms the connecting link between the ocean and every part of those distant realms.

CHAPTER XXI.

THE MOVEMENTS OF THE PLANETS.

The System of the World.

AN EXTENDED APPLICATION OF THE LAWS OF GRAVITATION DEMONSTRATED BY NEWTON'S 'PRINCIPIA' AND 'SYSTEM OF THE WORLD.'

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XIX. The revolving force of the Sun's gravitation in the orbits of the planets is directly as the ratio which the velocities of the orbital and lagging motions bear to each other in each orbit respectively.

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XXII. The ratio of the relative velocities of orbital and apparent motions is as the square root of the ratio of the forces of gravitation by which they are caused.

XXIII. The orbital motions of the planets are caused by the revolving action of the Sun's gravitation, and the apparent motions by the retarding action of astral gravitation.

XXIV. The revolving force of the Sun's gravitation, decreasing inversely as the cube of the distance, makes the relative velocities with which the planets perform their orbital revolutions round the Sun to be as the cubes of the velocities of the motion along the respective orbits in which the revolutions are made.

XXV. The distances of the planets from the Sun are regulated by the action of astral gravitation.

XXVI. To apply Proposition XXV. to the motion of a spinning-top.

PROPOSITION I.[1]

Theorem.—If one of any two bodies in space be moved in such a manner as to increase the distance between the two, the other tends to follow with the same motion.

Because the force of gravitation tends to hold them together, and, therefore, if one be moved by an extraneous force, the other is drawn in the same direction by the action of their gravitation towards each other.

Corollary.—For the same reason the gravitation towards other bodies will tend to keep the second body in its position ; and, therefore, between the two forces it can neither remain at rest nor move with the full velocity of the first.

[1] It must be borne in mind that the theory under demonstration in this Book is one arrived at by induction from the investigation of the movements of the ocean, not invented for the purpose of explaining the cause of the movements of the planets. From the movements of the latter corroborative evidence of the truth of what I consider already established as the cause of the movements of the ocean is given in such a manner that the result arrived at shows that the conflicting action of terrestrial and astral gravitation is of necessity tending to cause the system of oceanic circulation described in Book II.

PROPOSITION II.

Theorem.—The rotation of a sphere tends to cause surrounding bodies to revolve around it.

Because, at any point outside the sphere, the force of the gravitation of the nearest part is greater than that of any other equal part; and therefore the gravitation of the body at the given point towards the nearest part of the sphere will tend to cause it to follow the motion of that part.

Note.—By the corollary to Proposition I. the velocity of a body moved by the gravitation of another body in motion cannot be so great as that of the latter; and therefore, if the motion were in a right line, the motive force would gradually be decreased by the increasing distance. But as regards the rotation of the sphere, though the body set in motion cannot keep pace with the velocity of rotation, its recession from one part brings it over another part of the rotating surface; and thus the motive force becomes as constant and equable as the rotation.

PROPOSITION III.

Theorem.—The ratio which the revolving force of the gravitation of a sphere bears to its direct force is inversely as the distance from the sphere.

Because the revolving force depends on the amount by which the force of the gravitation of the nearer exceeds that of the remoter half of the sphere. Therefore, the difference in those forces depends on the ratio which the distance from the sphere bears to its diameter; increasing as the ratio which the diameter of the sphere bears to the distance from the sphere increases. And, as the ratio which the diameter bears to the distance is inversely as the distance, therefore the ratio which the revolving force of the gravitation of a sphere bears to its direct force is inversely as the distance from the sphere.

Definition.—The point from which the relative distances must be measured is neither the nearest point of the sphere nor its centre, but an intermediate point. The table on page 82, however, shows that for our present purposes the above ratio is sufficiently accurate if the relative distances be measured from the centre of the sphere, and the subject need not, therefore, be involved with that

minor question until, after elucidating the general principles, greater accuracy becomes requisite for matters of detail.

Corollary.—Subject to the foregoing Definition, the fraction of the sun's direct force of gravitation at any distance, which acts as a revolving force, is inversely as the distance, as shown by the table on page 82, as regards the actual distances of the planets from the sun.

PROPOSITION IV.

Theorem.—The revolving force of the gravitation of a sphere is inversely as the cube of the distance from it.

Because the direct force of gravitation is inversely as the square of the distance, and the ratio which the revolving force bears to the direct force is inversely as the distance (Proposition III.); therefore the revolving force of the gravitation of a sphere is, at different distances, inversely as the cubes of the distances.[1]

[1] This is demonstrated also by the Table of Forces and Velocities given in Proposition XIX., which also shows the slight difference in the ratio of forces, at the actual distances of the planets, acting from the centres of the opposite hemispheres of the sun and from the surfaces of the same.

Note.—If the movements of the planets accorded exactly with Kepler's empirical laws, then they would also accord exactly with the theoretical action described by the Propositions in this Book with the relative distances calculated from the centre of the sun; but those laws require correction, because the direct force of the sun's gravitation must be calculated from the centre of the sun, whereas the revolving force is dependent on the centre of gravity of the nearer half of the sun. This observation applies to all the Propositions in this Book in which the revolving force is involved.

PROPOSITION V.

Theorem.—The squares of the velocities of the orbital motions of the planets are to each other directly as the ratios which the revolving force of the sun's gravitation bears to its direct force in their respective orbits.

For the ratios are inversely as the distances (Proposition III.), and the velocities, measured along the respective orbits, are such that the squares of the velocities are inversely as the relative distances of the planets from the sun; therefore the squares of

the velocities are directly as the ratios which the revolving bears to the direct force.

Note.—The above is made evident by the table on page 82; for the fractions of the sun's direct force, which act as revolving forces, given in the third column of that table, are inversely as the mean of the distances given in the first column approximately; and the figures in the fourth column, which represent the actual relative velocities of the planets, are the square roots of those fractions of the sun's force.

PROPOSITION VI.

Theorem.—The squares of the relative velocities with which the planets in their orbital motions pass round the sun are to each other directly as the revolving force of the sun's gravitation in their respective orbits.

For the relative velocities of revolution are inversely as the times of revolution:

And the squares of the times are directly as the cubes of the distances (Kepler's law):

Therefore the squares of the velocities are inversely as the cubes of the distances.

But the revolving force is inversely as the cubes

of the distances (Prop. IV.) ; therefore the squares of the velocities are directly as the revolving force.

Definition.—The velocity of revolution must not be confounded with the velocity of motion.

The former applies to the relative number of revolutions, and the latter to the relative velocities of the motions by which the revolutions are effected. So that the relative velocities of revolution must be multiplied by the relative distances to give the relative velocities of motion.

PROPOSITION VII.

Theorem.—If vis-inertiæ, or a force of inertion inherent in matter, be the cause of gravitation, the moon must have both an apparent lagging motion and an orbital motion.

Because vis-inertiæ, being the cause of the entire force of gravitation acting at any point; when any part of that force of gravitation tends to give a body at that point a new position, it is evident that the position to which the body is moved under its action must be intermediate between that to which the motive force of gravitation tends to carry it and that in which the remaining force tends to retain it;

and therefore, whilst vis-inertiæ keeps it in equilibrium between these opposing forces, the body will neither reach the new position to which the motive force tends to carry it, nor remain in the old position in which the remainder of the force of gravitation tends to retain it. So that it must have a real motion from the old position, but at the same time can never reach the point to which the motive force endeavours to carry it.

Therefore, whilst held in equilibrium by vis-inertiæ, the moon has a real motion in the same direction as that of the motive force, which latter is its gravitation towards the nearest part of the earth's surface endeavouring to carry it along with the motion of that surface (Proposition II.): but the remaining force of gravitation, which is astral gravitation, as defined in Book III., keeps it constantly from reaching the point to which the motive force endeavours to carry it; and therefore gives it an apparent motion over the earth's surface in the opposite direction to that in which the surface endeavours to carry it.

PROPOSITION VIII.

Theorem.—If the planets as they revolve in their orbits are in equilibrium between the revolving force of the sun's gravitation, tending to carry them

onwards, and the opposing action of astral gravitation, then the force of astral gravitation increases as the square of the velocity of revolution which it opposes.

Because, being in equilibrium, the force of astral gravitation is equal to the revolving force ;

But the revolving force is as the square of the velocity of revolution (Proposition VI.) :

Therefore the force of astral gravitation increases as the square of the velocity of revolution which it resists.

Note.—The action of astral gravitation which opposes the revolving force is a centrifugal force ; because, acting in exactly the opposite direction to that in which the revolving force acts, it tends to draw the revolving body backwards out of its orbit, as shown by the diagram on p. 88.

PROPOSITION IX.

Theorem.—The direct force of the sun's gravitation acts as a retarding force, opposing its revolving force along the orbits of the planets.

Because the planets move along their orbits with such velocities of absolute motion as to make the

squares of those velocities identical with the fractions of the sun's force of gravitation which acts as a motive force along the respective orbits (p. 82); and those fractions are inversely as the distance from the sun (Proposition III., *Corollary*); whereas the absolute amount of the revolving force is inversely as the cube of the distance (Proposition IV.), and if not neutralised by the direct force of the sun's gravitation, inversely as the square of the distance would give to the planets, moving in comparatively free space, a much greater proportionate velocity with each decrease of distance.

Therefore, just as any force exerted to move any body along the surface of the earth is resisted by the weight of the body moved, which is the direct force of the gravitation of the earth acting on it, so also must the planets be held in equilibrium between the sun's direct force of gravitation and opposing force, which jointly resist motion along the orbit, as well as respectively in either direction from the orbit.

PROPOSITION X.

Theorem.—The direct force of the sun's gravitation tends to retard the sun's axial rotation more than the revolution of the planets.

Because, whatever be the distance from the sun's centre from which the revolving force acts, causing the sun to rotate in the plane of its equator, the velocity which it tends to give to matter in the plane of the equator is checked by the connection of the latter with that extending to the polar regions ; because the force acting from the opposite sides, W and E (Fig. 20), exactly neutralise each other at the poles, N and S,

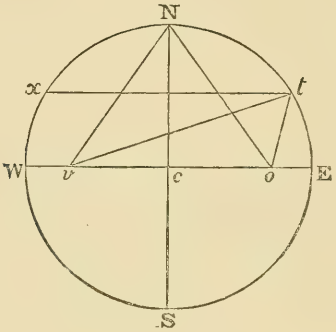


Fig. 20.

and have each their greatest effective action along the equator ; therefore the direct force of the sun's gravitation acting from the opposite hemispheres, N and S, towards the centre, C, causes those opposite hemispheres to act as a break, retarding the normal velocity which the revolving force would otherwise give to the equatorial regions.[1]

[1] The geological action of this retarding force is alluded to in several parts of *The New Principles of Natural Philosophy*.

PROPOSITION XI.

Theorem.—The retarding action indicated by the foregoing Proposition is apparent as regards the axial rotation of the sun, and also as regards the axial rotations of the earth and of the planets Saturn and Mars.

As regards the sun; because the velocity indicated by the relative velocities of planetary motions, which make the squares of their periods as the cubes of their distances from the centre of the sun, would give a planet at the sun's surface a period of ·1169 of a day instead of 28 days.

As regards the earth; because the velocity indicated in the same manner by the motion of the moon would give the earth's equator a period of 80 minutes instead of 24 hours.

As regards Saturn; because its rings, extended round the plane of its equator, and not checked by matter extending to the polar regions, revolve in a shorter period than the surface of Saturn below them.

As regards Mars; because its moon is in fact sufficiently near to it to be carried round in a shorter period than that of the rotation of the surface of Mars.

PROPOSITION XII.

Theorem.—The ratio which the vis-inertiæ of the planets bears to the direct force of the sun's gravitation is as the square of the distance from the sun.

Because vis-inertiæ is the source of every force of gravitation, or the whole action of the gravitation of the universe (Book III.) : [1]

And the direct force of the sun's gravitation is inversely as the square of the distance from the sun :

Therefore the ratio which vis-inertiæ bears to the direct force of the sun's gravitation is as the square of the distance from the sun.

PROPOSITION XIII.

Theorem.—The ratio which the vis-inertiæ of the planets bears to the sun's revolving force is as the cube of the distance from the sun.

By the same argument which makes the ratio it bears the direct force as the square of the distance

[1] See Proposition XXXII.

(Proposition XII.); for the revolving force is inversely as the cube of the distance from the sun (Proposition IV.)

PROPOSITION XIV.

Theorem.—The ratio which the vis-inertiæ of the planets bears to the combined action of the direct and revolving forces of the sun's gravitation is as the fifth power of the distance from the sun.

Because the normal ratio of the square of the distance which vis-inertiæ bears to the sun's direct force is increased as the cube of the distance by the existence of the revolving force.

PROPOSITION XV.

Theorem.—The combined action of the direct force and the revolving force of the sun's gravitation makes its motive action along the orbits of the planets inversely as the relative distances.

Because the sun's revolving force is inversely as the cube of the distance from the sun (Proposition

IV.) ; and the direct force, which is inversely as the square of the distance, is a retarding force (Proposition X.)

Note.—The sun's revolving force, endeavouring to carry the planets round with the same motion, is inversely as the cube of the distance from the sun (Proposition IV.), and the planets are revolved with such relative velocities as to make the squares of those velocities of revolution identical with the relative amount of the sun's revolving force in their respective orbits (Proposition VI.) But the fraction of the sun's direct force in each orbit which acts as a revolving force is inversely as the distance from the sun (Proposition III., *Corollary*), and the squares of the relative velocities with which the planets move along their orbits are identical with the respective fractions of the sun's direct force which act as revolving forces along the orbits (Proposition V., *Note*). And these fractions of the sun's direct force represent its motive action along the orbits of the planets, because the increased force of any given fraction, consequent on a decrease of distance from the sun, is to the same extent counterbalanced in consequence of the direct force forming a part of the retarding force of gravitation, which resists the onward motion along the orbit.

Corollary 1.—If the planets are moved along their orbits in equilibrium between opposing forces of

gravitation, then the force of astral gravitation which resists the sun's motive action along the orbit is as the square of the velocity of motion.

Corollary 2.—By the above and Proposition VIII. the resistance of astral gravitation is as the square of the velocity it opposes, whether it be a velocity of revolution or a velocity of motion.

This is to be inferred also from the centrifugal force being equal to the centripetal, and therefore inversely as the square of the distance from the sun; so that the remainder of the retarding force which opposes the sun's revolving force is inversely as the distance.

PROPOSITION XVI.

Theorem.—The ratio which the motive force of gravitation, acting along the orbits of the planets, bears to the relative vis-inertiæ of the planets in respect to the sun's direct force is as the sixth power of the distance.

Because the one is inversely as the distance (Proposition XV.), and the other directly as the fifth power of the distance (Proposition XIV.)

PROPOSITION XVII.

Data.—The sun's revolving force endeavours to revolve the planets in equal periods.

Definition.—The superimposed objects N and M (Fig. 21), resting at A on the earth's surface, E A W, are revolved about the earth's centre, C, in equal periods; the more distant, N, moving in a greater orbit, and with a greater velocity of motion, than M.

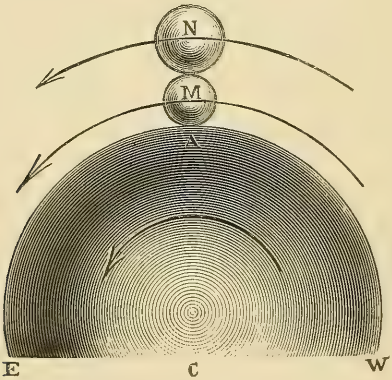


Fig. 21.

Theorem.—Those attempted velocities are decreased as the square roots of the sun's revolving force in the respective orbits decrease.

Proof.—For the endeavour to carry Neptune round in the same period as Mercury would give the former a velocity of motion 77·7 times greater than the latter. But the revolving force being inversely as the cube of the distance, and therefore 469000 times greater in the orbit of Mercury, and increasing its velocity as the square root of the force, or diminishing the relative velocity of Neptune in that proportion, would therefore decrease the relative velocity of the latter 684 times, making the relative velocities as 1 is to $\frac{77\cdot7}{684}$; or as 8·8 is to 1; which are the actual relative velocities of motion along the respective orbits.

Note.—Books II. to VIII. have shown that the drops of water in the ocean, instead of keeping pace equably with the earth's rotation, tend to lag more at the surface of the ocean in the equatorial regions than below the surface where nearer the earth's centre; and the above Proposition shows that the relative lagging of the planets in relation to the sun's rotation accords mathematically with the action of the forces described as circulating the ocean.

PROPOSITION XVIII.

Problem.—To determine the normal period in which the force which causes the sun's rotation endeavours to revolve the planets, as indicated by the actual relative periods in which they perform their orbital revolutions.

If the revolving force be supposed to act from a mathematical point in the centre of the sun, then, as the actual periods decrease as the square root of the cube of the distance decreases, both the actual and the attempted periods would at that point be infinitely decreased, making the effort of gravitation to be, to give the planets an infinite number of revolutions in an infinitely short period.

A slight removal of the source of the revolving force from the centre of the sun allows of the existence of a definite period of attempted revolution, and the greater that distance the greater the period.

Allowing the maximum distance from which the sun's gravitation can act, which is from the surface of the sun, the period would then be ·1169 of a day.

The normal period sought for is therefore between the two extremes above indicated.

PROPOSITION XIX.

Theorem.—The revolving force of the sun's gravitation in the orbits of the planets is directly as the ratio which the velocities of the orbital and lagging motions bear to each other in each orbit respectively.

Because the revolving force resulting from the difference in the motive action of any two particles in opposite hemispheres of the sun at corresponding points in those hemispheres is inversely as the cube of the planet's distance from the sun: for it is shown by the table annexed that the ratio of forces acting from R and S, close to the surface of the sun, differs so little from that acting from Y and Z, near the respective centres of the opposite hemispheres, that for the purpose of the present argument the aggregate action of the two opposite hemispheres at the actual distance of the planets may be treated as inversely as the cube of the distance from the sun. And, by the same table, the ratio of velocities also closely approximates to the inverse cube of the distance with the minimum lagging velocity indicated by the foregoing Proposition; and a greater lagging velocity would make the ratio of velocities more nearly approximate to the inverse cube of the distance calculated from the centre

FORCES 'Y' AND 'Z' IN PLATE XVII., page 223.

	Distance from 'A,' sun's centre 1=1,000,000 miles	Distance from 'Y' in nearest hemisphere of sun	Distance from 'Z' in farthest hemisphere of sun	Relative distances inversely		Squares of relative distances inversely, showing relative amounts of force at each distance		Differences of foregoing forces	Same 1=force in orbit of Neptune
Mercury . .	36·725	36·503	36·947	502432	496396	252437914624	246408988816	6028925808	468990
Earth . .	95	94·778	95·222	193508	192606	37445346064	37097677236	347668828	27040
Neptune . .	2853·42	2853·198	2853·642	6428	6427	41319184	41306329	12855	1

FORCES 'R' AND 'S.'

	Distance from 'R,' nearest side of sun	Distance from 'S,' farthest side of sun	Relative distances inversely		Squares of relative distances inversely, showing relative amounts of force at each distance		Differences of foregoing forces	Same 1=force in orbit of Neptune
Mercury	36·281	37·169	252734	246696	63874474756	60858916416	3015558340	469200
Earth	94·556	95·444	96973	96071	9403762729	9229637041	174125688	27090
Neptune	2852·976	2853·864	3214	3213	10329796	10323369	6427	1

VELOCITIES.

	Velocities of orbital motions per ·1169 of day 1=444,000 miles × 6·28	Lagging per ·1169 of day in relation to normal revolution 1=444,000 miles × 6·28	Ratio of onward motion and lagging	Distance lost during each orbital revolution, 1=444,000 miles × 6·28	Ratio of velocity of orbital motion to distance lost during each orbital revolution	Same 1=ratio in orbit of Neptune
Normal . .	1	0	as 1 is to 0	0 × 1 = 0		
X.	0·79	0·79	„ 1 „ 1	1 × 1·58 = 1·58	0·5	
Mercury .	0·10995	82·6	„ 1 „ 751·2	751·2 × 82·71 = 62130	0·000001769	469400
Earth . .	0·068382	213·83	„ 1 „ 3127	3127 × 213·9 = 668800	0·0000001022	27120
Neptune .	0·012475	6425·98	„ 1 „ 515100	515100 × 6426 = 3310000000	0·00000000003768	1

of the sun. For by treating the attempted velocity as infinite, the table would give the maximum velocities of lagging, which would make the relative periods of revolution exactly the measure of the relative velocities of lagging.

No actual proof that this latter is not the measure of the relative lagging velocity is yet given, except the fact that it seems scarcely reasonable to suppose that it can be so ; and it appears most probable that the revolving force acts from what at any given instant may be the centre of gravity of the nearer hemisphere of the sun. And as this would give a still greater velocity of lagging than that indicated in the table, and therefore be intermediate between the *maximum*, obtained by treating the periods of revolution as exactly the measure of the relative lagging, and the *minimum*, obtained as shown by the table ; and as those extremes do not themselves differ sufficiently to affect the purpose of the present arguments, the simple ratio indicated by the periods of revolution may (until greater precision is required for questions of detail) be treated as the measure of the lagging velocities.

Therefore, as the apparent velocity of Mercury's orbital motion is 14732″ per day and that of Neptune $21\frac{1}{2}''$; the former revolves in 88 days and the latter in 60126 days ; and the ratio of orbital motion and lagging is approximately as given in the following table :—

APPARENT VELOCITIES.

	Periods of orbital revolution in days	Mean daily motion, or apparent velocities	Ratios of apparent velocities to periods of revolution	Same, 1=ratio in orbit of Neptune
Mercury . . .	87·96	14732·4″	167·47	467200
Venus	224·7	5767·6	25·712	71740
Earth	365·25	3548·19	9·714	27100
Mars	686·9	1886·5	2·7463	7660
Jupiter . . .	4332·5	299·12	·06904	192
Saturn . . .	10759·2	120·455	·011196	31
Uranus . . .	30686	42·233	·0013762	3·8
Neptune . . .	60126	21·554	·0003584	1

The ratios above are inversely as the cubes of the distances of the planets from the sun, or directly as the sun's revolving force in each orbit (approximately), as shown by the table on p. 246.

The ratios of real velocities and lagging, with the maximum correction for the latter alluded to in Proposition III., is also given in the table just mentioned.

PROPOSITION XX.

Theorem.—The relative velocities of the lagging motions of the planets are as the square roots of the ratio which vis-inertiæ bears to the direct and revolving force of the sun's gravitation in their respective orbits.

For the ratio of forces is as the fifth power of the distance (Proposition XIV.)

But Neptune lags 683 revolutions whilst Mercury lags one; and the length of its orbit is 77 times greater; so that the velocity of its lagging motion is 52,591 times greater. The square of this increased velocity is 2,765,813,281, which is approximately the fifth power of the distance.

Note.—In the above (for the reason given in the Note to the foregoing Proposition) the relative periods of revolution are taken as the measure of the relative velocities of the lagging motions, making Neptune's lagging approximately 683 revolutions more than Mercury's, because the latter takes about 88 days to revolve and the former 60,126 days. The limit of the correction which may be requisite, and which is not, even at its maximum, enough to affect the present argument, is shown in connection with the foregoing Proposition.

PROPOSITION XXI.

Theorem.—The relative velocities of absolute motion with which the planets move along their orbits are to each other directly as the square roots of the fractions of the sun's force of gravitation, which act as revolving forces in each orbit respectively.[1]

[1] This is a corollary to Proposition III.

The fractions of the sun's direct force which act as revolving forces are inversely as the distance (Proposition III., *Corollary*).

But Mercury makes 683 orbital revolutions whilst Neptune makes one; and the length of Neptune's orbit being 77 times greater than that of Mercury, the velocity of Mercury's orbital motion is 8·8 times greater than Neptune's. The square of this increased velocity is 77·44, which is, approximately, inversely as the difference of the relative distances.

Note.—The above is demonstrated also by the table on p. 82, which shows that the fraction of the sun's force which at any distance acts as a revolving force is inversely as the distance, and directly as the squares of the velocities of motion in the planetary orbits.

PROPOSITION XXII.

Theorem.—The ratio which the motive force of gravitation bears to the vis-inertiæ of the planets in each orbit is as the square of the ratio which the velocities of the orbital and lagging motions bear to each other.

For the velocity of Mercury's orbital motion is 8·8 times greater than Neptune's; and the velocity

of Neptune's lagging motion is 52,591 times greater than Mercury's:

Therefore the ratio which the orbital bears to the lagging motion is 463,350 times greater in the orbit of Mercury than in that of Neptune.

The square of that ratio of velocities is 214,693,222,500—which is approximately the sixth power of the distance, and therefore represents the relative ratio of forces (Proposition XVI.)

PROPOSITION XXIII.

Data.—The sun rotates from west to east, and the planets revolve in their orbits in the same direction; but the periods of their revolution are greater than that of the sun's rotation, so that they have apparent motions over the surface of the sun from east to west.

Theorem.—The motions by which the planets are revolved in their orbits from west to east round the sun are caused by the revolving force of the gravitation of the latter, tending as it rotates to carry the planets round with it in the same motion of rotation; and the apparent motions from east to west, in relation to the surface of the sun, are caused by astral gravitation.

Because the opposing action of solar and astral gravitation tends to give the planets both orbital and apparent motions (Proposition VII.) ;

And the actual relative velocities of the opposite motions in each orbit are neither greater nor less than would result from the free action of those forces (Propositions XIX. to XXII.) :

Therefore those motions are not dependent on the action of any other forces than those stated in the above theorem.

Note.—Extraneous forces, acting from other centres of rotation, may revolve the whole solar system jointly, and cause perturbations in the motions of the planets under consideration in this Proposition ; but the acceleration in one part of the orbit being compensated by the retardation in the opposite part, the mean velocities will not be affected.

PROPOSITION XXIV.

Theorem.—The revolving force of the sun's gravitation, decreasing inversely as the cube of the distance, makes the relative velocities with which the planets perform their orbital revolutions round the sun to be as the cubes of the velocities of the motions along the orbits in which the orbital revolutions are made.

For the foregoing Propositions show the sun's revolving force to be the cause of the orbital revolutions of the planets ; and Plate XVII. shows the existence of that ratio of real and apparent velocities of orbital motion as regards Mercury and the earth ; and the same ratio exists as regards all the planets.

Thus, the relative velocities of the orbital motions of Mercury and Neptune are as 8·8 is to 1 ; the cubes of those velocities are as 681 is to 1 ; which represents approximately the relative number of their orbital revolutions.

Also, because the revolving force is inversely as the cube of the distance (Proposition IV.) and the motive force acting along the orbit is inversely as the distance (Proposition XV.) ; therefore the relative number of revolutions are as the cubes of the relative velocities of motion.

PROPOSITION XXV.

Theorem.—The distances from the sun at which the planets are revolved in their orbits are determined by the action of astral gravitation.

Data.—The planets are revolved in their orbits in equilibrium between opposing forces of solar and astral gravitation.

Proof.—Let any planet in any given position be in equilibrium without an orbital motion, and then let the revolving force of the sun's gravitation tend to give it any given velocity of revolution.

The force of astral gravitation then increases as the square of that velocity (Proposition VIII.):

The equilibrium between the opposing forces of solar and astral gravitation is then destroyed, and the planet must therefore move in the direction of the greater force, which consequently carries it farther from the sun :

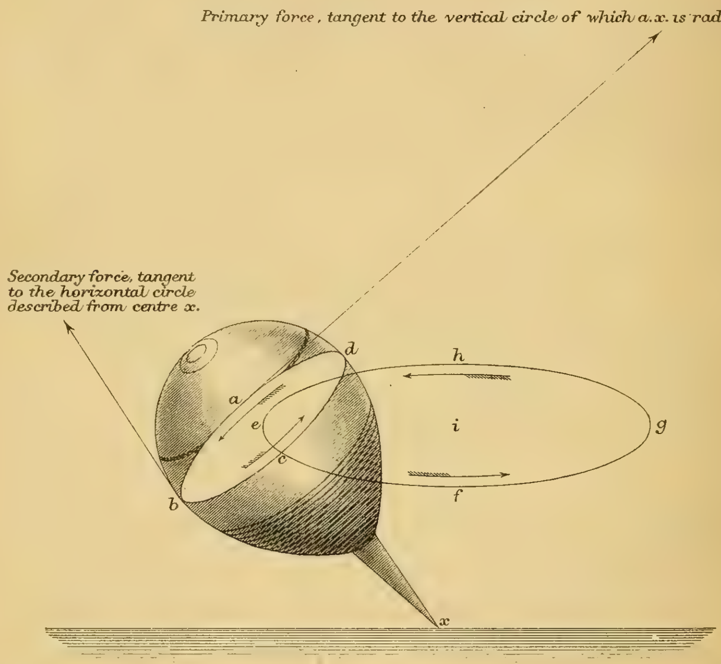
As it recedes from the sun, the power of the direct force of the latter to retain it in its orbit decreases as the square of the distance increases:

But the revolving force decreases as the cube of the distance increases (Proposition IV.): and the opposing force of astral gravitation decreases in the same proportion :

Therefore, since the greater force, tending to carry the planet out of its orbit, decreases as the *cube* of the distance increases ; whilst the lesser force, tending to retain it in its orbit, decreases as the *square* of the distance increases ; the recession of the planet from the sun must sooner or later restore the equilibrium of the opposing forces.

Therefore the distance to which the planet is carried from the sun is determined by the action of astral gravitation.

This demonstration is illustrated by the diagram



Edw^d Weller

London, Longmans & Co.

on p. 88. In consequence of the increase of the retarding force of astral gravitation the planet at *a* is carried to *c* in the orbit *c d e*, instead of moving from *a* to *b* in its former orbit, *a b f*. The increased force of astral gravitation thus *lifts* the planet into an orbit farther from the sun at *x*.

Note.—The planet having been held in equilibrium by vis-inertiæ, the whole of that force, except the force of astral gravitation created by the action of the revolving force, tends to keep it at its normal distance of equilibrium.

Corollary.—Therefore the action of a revolving sphere on other bodies in positions of normal equilibrium may be considered as exerting a centripetal force decreasing as the square of the distance, and a revolving force decreasing as the cube of the distance and of necessity resisted by a retarding and centrifugal force also decreasing in the latter proportion.

PROPOSITION XXVI.

Problem.—To apply Proposition XXV. to the motion of a spinning-top.

Suppose the velocity of rotation be, say, 8 in the direction *a b c d* (Plate XVIII.); if the resisting

force of astral gravitation is equal to the square of velocity, then the resistance of astral gravitation is as the square of 8 on each side; but immediately the top moves downwards from that position—say with the velocity of 4 in a downward direction—then the particles on the side *d a b*, with this motion added to them, have their velocity increased; and that velocity of 4 added to the velocity of 8 makes the velocity of 12, whereas the velocity on the side *b c d* is reduced to 4; so that the resistance of astral gravitation on one side is the square of 4, or say 16, whereas the force on the other side is 144, say the square of 12; so that the force of astral gravitation on the side *d a b* is 144 drawing upwards and 16 on the side *b c d* drawing downwards. Thus there is a difference of 128, representing an excess in the force of astral gravitation drawing upwards; and, unless the earth's power of gravitation drawing it downwards is equal to that difference of 128, the top cannot fall; it is then supported, and it is only when the top's rotation becomes so slow that the earth's power of gravitation dragging it down is greater than the difference between those two forces of astral gravitation, that the top can fall.

The tangential action of the force at *a*, which supports the top (constantly lifting that side whilst the side *c* falls) carries the top round with the motion of revolution in the direction *e f g h*.

A force of astral gravitation at the point *b* then

resists this horizontal motion exactly as that at the point *a* resists the downward motion ; and the tangential action of the force at *b* also supports the top ; because it tends to carry the point *b* farther than the point *d*, from the centre *x*, just as the tangential action at the point *a* makes the top revolve by tending to carry the point *a* farther than the point *c* from the centre *x*.

If the velocity of rotation be great, the force at *b* will lift the top into an upright position in the same manner as the force at *a* carries the top round in the direction *e f g h*.

As soon as the velocity with which the top rotates becomes so slow that it falls, under the influence of the earth's gravitation, the onward motion communicated to it by the action of astral gravitation is immediately reversed, and it runs on the ground like a wheel.

PROPOSITION XXVII.

Problem.—To apply Proposition XXV. to the upheaval of the ocean round the equatorial regions by the action of the earth's rotation and to its constant circulation in that position.

1. Let the circle N W S E (Fig. 22) be the surface of the earth, N the north, and S the south

pole. And let the circle *a b c d* be the form which the ocean would take with the earth at rest.

Then give the earth an axial rotation in the plane of the equator, W E.

This rotation creates a centrifugal force which gives the particles of water resting on each parallel of latitude a tendency to rise from the circles in which they are revolved.

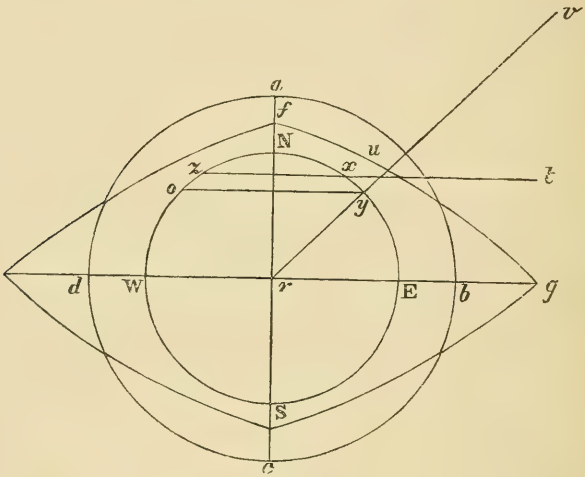


Fig. 22.

Thus, under the action of the centrifugal force, particles on the equator, W E, tend to rise from E towards *g* in the plane of the equator; and particles on the parallel *z x* tend to rise in the direction *x t*, parallel to the equator. But the earth's gravitation, acting across the plane *x t* in the direction *v r*, draws the latter particles towards the equator.

Thus, as the centrifugal force tends to carry off

the particles in the plane of rotation, *z x*, the earth's gravitation inclines them out of that plane into the next parallel of greater circumference, *o y*, where the centrifugal force is augmented ; and pressing in this manner through each parallel of latitude towards the equator, they replace the particles at E, whose centrifugal force, augmented by the pressure of the particles from *x*, carries them towards *b* and *g*.

Thus the water sinks from *a* to N, glides along the surface of the earth from N to E, and rises upwards from E to *g*.

The centrifugal tendency imparted by the rotating surface of the earth increases as any particle travels from N to E ; but as it rises from E to *g* it gradually loses the centrifugal impetus which caused it to fly off from the surface at E (for its motion is retarded, as shown in Proposition XXV. of the planet moved from the orbit *a b f* to the higher orbit *c d e* in Fig. 19, p. 88), and as the particles raised up towards *g* lose their centrifugal force, their gravitation to the earth must tend to restore the equilibrium of the ocean, making the pressure of the column E *g* at E equal to the pressure of N *f* at N.

2. As the centrifugal force continues to act on the particles resting on the surface of the earth tending to carry them from N (Fig. 22) through *x y* to E and *b*, they prevent the particles at *g* from falling to the earth in a direct line ; and therefore as the centrifugal force of the particles at *x* tends to cause them

to displace those at E, and that of the particles at E tends to cause them to displace those at g, the latter are by the earth's gravitation (being released from the immediate action of the centrifugal force) drawn back towards f, and thus supply the sinking motion from f to N.

A constant circulation in the directon E g f N E is thus established with the ocean in equilibrium.

3. Also, because, being less firmly held by the earth's gravitation, the particles in the line f u are more free to flow towards the equator under the action of the centrifugal force, than those in the line N y; therefore, there is a tendency to a circulation in the direction y N f u g E y.

But, as the excess of this horizontal force, tending to cause a circulation with an upward motion about the poles, is greatest in the polar regions, and decreases gradually towards the equator, where it ceases to act; and the excess of the vertical force previously described as tending to cause a circulation with an upward motion about the equator, is greatest in the equatorial regions, and decreases gradually towards the pole, where it ceases to act; therefore, the sinking motion must be in an intermediate latitude with a circulation in the direction u y N f u in the polar regions, and in the direction u y E g u in the equatorial regions.

4. Also, because the retarding and centrifugal force of astral gravitation, being as the square of the

velocity of rotation, is greater along the equator W.E. than along the parallel *o y*, the ratio which the earth's force, drawing downwards and eastwards, bears to the astral force drawing upwards and westwards, is greater along the parallel *o y* than along the equator W.E.; therefore there is a circulation across the meridian *a r* eastwards, as well as downwards, along the parallel *o y*, and westwards, as well as upwards, along the equator E.W.

And the eastward motion across the meridian is in latitudes intermediate between the equatorial and the polar regions, and not in the highest polar regions, because in the vicinity of N. (Fig. 20 in Proposition X.) the revolving forces acting from *v* and *o* neutralise each other (as shown by Proposition X.) leaving the retarding force little resisted by the direct action of the revolving force; but farther from the pole, as at *t*, Fig. 20, the normal eastward velocity is increased by the excess of force acting from *o* and E over that acting from *v* and W. Therefore, whilst the water lags westwards in the equatorial and in the polar regions under the retarding action of the astral force, it is carried eastwards through the temperate zones by the relative excess of the revolving action of the terrestrial force.

5. Also, let T, in Fig. 23, be a point on the 45th parallel, and let *o*, the source of the revolving force, in the equatorial radius C E be so placed that O T be to O E as 1·2 is to 1. The revolving force at

E is to the same at T as 1·72 is to 1 (being inversely as the cube of the distance). And the resulting velocities, being as the square roots of the respective forces, would be as 1·312 is to 1, making the velocity at T ·76 of the velocity at E. But the length of the parallel at T is only ·71 of the length of that at E on the equator; and therefore a revolving force acting

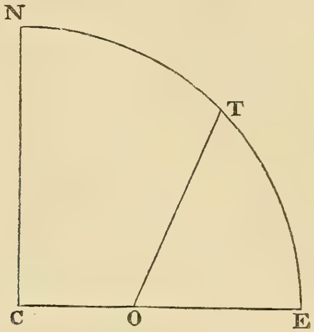


Fig. 23.

from O, sufficient to give the water at E the equatorial velocity, would give to the water at T a greater velocity than that of the surface of the earth at T.

6. Or, since the velocity of motion at the equator is 1,000 miles an hour, and on the 45th parallel 710 miles an hour; and since the retarding action of astral gravitation is as the square of the velocity; therefore the relative retarding action is—

At the Equator . . .	1,000,000
On the 45th parallel . . .	504,100

But, as shown in the foregoing section, the relative revolving force in the same positions is as 1·72 is to 1,

and therefore the revolving force being at the equator 1,000,000, it is on the 45th parallel 581,000.

There is therefore a relative excess of revolving action on the 45th parallel ; for the normal amount of retarding force on the 45th parallel is ·504, and the revolving force ·581 of the same forces respectively on the equator if the source of the revolving force be as given in the foregoing section.

PROPOSITION XXVIII.

Theorem.—If any force inherent in a planet, or any extraneous force continuously acting on it, tended to give it a faster motion in its orbit than that imparted by the revolving force of the sun's gravitation, that planet could not remain in the solar system.

Data.—Proposition XXV.

Proof.—Because, however slight the increase of velocity, the equilibrium in the orbit is destroyed by the centrifugal force increasing as the square of the velocity : and as the planet, whilst increasing the velocity of its onward motion, recedes from the centre under the action of the opposing force, the opposing forces become more and more unequal ; for

the motive force, being independent of the sun, does not decrease as the distance from it increases ; whereas the power of the sun's gravitation to retain the planet does constantly decrease : therefore a planet acted on by such a force could not be retained within the solar system.

PROPOSITION XXIX.

Theorem.—Objects lying loosely on the surface of a rotating sphere, of which the direct force of gravitation is greater than the revolving force, will rest upon it, but at the same time have relative motions along the surface.

Because the objects would be held to the surface by the direct force of gravitation ; but on the surface, if free to move, vis-inertiæ would determine their positions between the conflicting forces of astral gravitation and the revolving force of gravitation (Proposition VII.), and so give them a relative motion along the surface.

Note.—Bricks, even loosely piled, are too firmly held by the direct force of the earth's gravitation to be sufficiently free to move ; but the drops of water superimposed on each other in the ocean are inces-

santly exchanging their positions as the ratio of the conflicting forces varies at different depths or in different parts of the ocean.

PROPOSITION XXX.

Theorem.—If the revolving force of a sphere be greater than its direct force, nothing can rest loosely on its surface.

Because the centrifugal force of astral gravitation is equal to the revolving force (Proposition VIII.) ;

Therefore objects placed on the surface are carried from it by astral gravitation sufficiently far to bring this into equilibrium with the direct force (Proposition XXV.)

PROPOSITION XXXI.

Theorem.—The revolving force of the earth's gravitation, and the force of astral gravitation which resists the direct force of the earth's gravitation in the absence of any revolving force, are together less than the direct force of the earth's gravitation

at all points within a distance from the earth's surface at least as great as the limits of the atmosphere.

Because objects within at least those limits are drawn to the earth's surface by the force of gravitation; therefore the force drawing towards the earth is greater than that drawing from it:

But the force drawing from the earth is the normal force which opposes the direct force of the earth's gravitation increased by that which opposes the motion caused by the revolving force:

Therefore these two are together less than the direct force.

But the force drawing from the earth in consequence of the action of the revolving force is equal to the revolving force:

Therefore the sun's revolving force and the normal force of astral gravitation are, within those limits, less than the direct force of the earth's gravitation.

PROPOSITION XXXII.

Theorem.—At some certain distance from the earth the direct force of its gravitation must be brought into a state of equilibrium as regards the combined

action of the forces of astral gravitation mentioned in the foregoing Proposition.

Because vis-inertiæ is the gravitation of the universe, of which the sun's direct force of gravitation is a part and astral gravitation the remainder;

Therefore the decrease of the solar force is the increase of the astral force; and therefore at some greater or lesser distance from the sun the opposing forces are equal.[1]

[1] We have said that, setting aside planetary influences, the earth in its orbit round the sun is held between the opposing forces of astral and solar gravitation. But, in fact, the astral gravitation which at any given point of the earth's orbit is acting in opposition to the sun, is at the opposite point of the orbit acting in conjunction with the sun, its force being there diminished in the inverse proportion to that in which the square of the distance at which it is acting is increased. Therefore, the astral gravitation acting in opposition to solar gravitation, is at any point of the earth's orbit equal to the force of solar gravitation, together with the force of astral gravitation which, by acting across the orbit of the earth, acts in conjunction with the sun. From which it follows, that the force of solar gravitation is equal to the amount by which the force of astral gravitation is diminished by the increase of its distance in acting across the orbit of the earth. Now, if we take into consideration only the mean distance of that part of the universe which the telescope has revealed to us—even taking that distance as the mean distance from which astral gravitation acts upon the solar system—even then, the difference in the force acting in the same direction at two opposite points of the earth's orbit causes an inexpressibly slight difference in the relation of those forces to each other: and since this difference is equal to the power of solar gravitation, this latter is, therefore, when compared with that of astral gravitation, insignificant beyond the power of mathematical expression. The comparison is as that of day with the entire duration of time, or as that of a mile with the

The distance at which they are equal forms the normal line of the equilibrium of vis-inertiæ.

This normal line of equilibrium is destroyed by the force of astral gravitation which opposes the sun's revolving force (Proposition XXV.)

But as this force of astral gravitation decreases inversely as the cube of the distance from the sun (Proposition XXV.);

Whilst the direct force of the sun's gravitation decreases inversely as the square;

Therefore the line of equilibrium will be reached at some greater distance from the sun, as already shown in Proposition XXV.

PROPOSITION XXXIII.

Theorem.—An indefinite number of successive lines of equilibrium separated by spaces, in which the forces of gravitation drawing towards and from the earth are unequal, might be formed in the same manner as that shown in the preceding Proposition.

Because bodies in the first line of equilibrium

entire extension of space. And yet to us these comparatively infinitesimal portions of power, of time, and of space are equally all-important.—*The Elements*: Longmans, Green & Co, London, 1866, vol. i. p. 89.

would there form in the space beyond them a fresh accession of gravitation acting towards the earth.

But by the decrease of this direct force and concomitant increase of the astral force, the opposing forces must again at some greater distance be brought into equilibrium.

The second normal line of equilibrium would be disturbed in the same manner as the first by the revolving force; and bodies in it would be carried farther from the earth by the astral force, until by the force drawing towards the earth decreasing as the square, and the revolving force decreasing as the cube of the distance increased (as shown in Proposition XXXII. of the first line of equilibrium), the equilibrium of the opposing forces would be restored.

Thus an indefinite number of successive lines of equilibrium might be formed at different distances from the earth.

PROPOSITION XXXIV.

Theorem.—The distance within which the revolving force of the earth's gravitation will be effective in causing surrounding bodies in space to revolve around the earth depends on the proximity and relative power of other revolving forces.

Because it is evident that, in the absence of any other revolving force, that of the earth would extend

the successive lines of equilibrium (Proposition XXV.), and would revolve all surrounding bodies with a force inversely as the cube of the distance from the earth (Proposition IV.) ;

Therefore, unless overwhelmed by the action of revolving forces acting from other centres of rotation, that of the earth would revolve the universe with the earth's rotation.

Corollary.—Therefore the revolving force of the earth's gravitation is constantly endeavouring to revolve the sun in the opposite direction to that in which the earth actually is revolved round the sun ;[1] but because the sun's revolving force is greater than that of the earth, therefore the earth is revolved round the sun. So also the sun revolves all the planets, because there is no greater force sufficiently near to overwhelm its action.

The solar system extends as far as its revolving force is greater than that proceeding from any other centre of rotation, and within which all bodies, being under its dominion, are revolved with it as planets.

The planetary systems extend to the limits within which any one of their revolving forces is greater than that of any of the other planets. Within those limits it revolves surrounding planets, whilst it and they are together revolved by the greater force of the sun's rotation.

[1] See the Chapter on the Secular Acceleration of the Moon's Motion in *The New Principles of Natural Philosophy.*

PROPOSITION XXXV.

Problem.—To determine the motion of a body in space under the action of revolving forces proceeding from different centres of rotation.

1. If a body in space be acted on equally by equal forces proceeding from two different centres of rotation, and tending to carry it in the same direction, it is evident that as it proceeds, and the directions of rotation diverge, it must take an intermediate course between the two, and therefore be equally carried away from both centres of rotation.

As it recedes it must, at some point equidistant from both centres, be brought into equilibrium as regards the centripetal and centrifugal forces: because it is carried off from both centres in consequence of the force of astral gravitation acting from them increasing as the square of the velocity (Proposition VIII.) is increased by the combined action of the two revolving forces; but, whilst carried off along a line forming a tangent to both of the orbits, the centripetal forces decrease as the square of the distance increases, whilst the centrifugal forces of astral gravitation which carry it off along that tangent (because in it they equally retard it from the positions on each side to which the revolving forces

tend to carry it) decrease as the cube of the distance increases (Proposition IV.) ; so that it must, sooner or later, be brought to rest between the conflicting forces.

But, if a third revolving force exist, the equilibrium must be destroyed ; because, whilst receding along the tangent, the body must be inclined by that third force towards the direction of one or other of the equal forces, and thus be caused to revolve with one or other of those centres of rotation.

2. If the equal action of the equal forces alluded to in Section 1 be in opposite directions, then the body under their action can neither advance nor recede, for the forces of astral gravitation, as well as the direct forces, neutralise each other.

But the action of a third force must incline the body towards one or other of the two equal forces ; and by that force it will then be revolved, increasing unequally its distance from both centres as the velocity of its motion is increased by the gradually decreasing opposition of the revolving forces.

3. Let us now suppose the revolving forces of Section 1 to be unequal, then the body lying between the two centres of rotation tending to carry it in the same direction is accelerated, and thus carried farther from both centres, until, as it inclines more and more in the direction of the primary force, the conjoint action ceases and becomes opposing ; and then, as the motion becomes retarded, it approaches its centre of

rotation until checked by the acceleration resulting from this approach.

4. And if the revolving forces of Section 2 be unequal, then the body lying between the two tending to carry it in opposite directions is retarded. But, as it is carried onwards with the course of the rotation of its primary, the revolving forces are in less and less direct opposition, and the motion becoming accelerated, the body recedes from both centres until the normal velocity and normal distance from both centres is arrived at, as one revolving force acts directly across the other.

There a conjoint action of the forces commences, causing acceleration, and consequently continued recession from both centres until the forces act completely in conjunction.

As it advances from that point the direct conjunction of the forces ceases, and the motion becomes gradually retarded, letting the body fall towards both centres until the normal velocity and distance from both centres is again attained, as the revolving forces act at right angles to each other.

There the opposition of the forces recommences. The retardation of the motion is increased, and the body consequently continues to approach both centres until the revolving forces are completely in opposition.

Then, as direct opposition gradually ceases, acceleration and recession from both centres recommence.

Thus, since the sun and earth rotate in the same direction, as also do the revolving forces under consideration in this section, therefore, according to the foregoing, if the planes of their rotation coincided, the radius of the moon's orbit round the earth pointing towards the sun would be shortened, and that pointing in the opposite direction lengthened, so that the line of the apsides would always point through the earth and sun ; because its position, lying from the point at which the revolving forces are in conjunction to that in which they are in opposition, would lead it through those bodies.

5. But, the planes of rotation being inclined, the sun's revolving force tends to throw the moon out of the plane of the earth's rotation, and, as it leaves that plane, the earth's revolving force decreases, allowing the moon to fall towards the earth. This action is reciprocal, and might attain its maximum in any part of the orbit, being dependent on the changing of the inclination.

Thus, instead of the moon's apogee and aphelion coinciding and occurring when the moon was at its greatest distance outside the orbit of the earth, as would be the case if the revolving forces acted in the same plane, they become dependent on the changing of the intersection of the planes of rotation. By the disturbing action of the changing inclination of these planes, the perigee and perihelion might both be thrown outside the orbit of the earth ; or the perigee

and aphelion might occur together outside; or the points of perigee and perihelion might be for ever changing their relative positions.

6. Throughout these problems we have dealt with the motions caused by the revolving forces and controlled by the forces of astral gravitation brought into action by the motions: but in those motions the heavenly bodies are held in equilibrium between the forces of astral gravitation and the direct forces of the gravitation of the bodies round which they are revolved; therefore the study of gravitation, as followed by Newton and subsequent astronomers, must show its action to harmonise with the motions caused by the revolving forces.

But as the laws of vis-inertiæ have indicated the cause of the motions which have been the objects of study, it is evident that the science of astronomy must be simplified and more easily extended by the use of this new power of reasoning from cause to effect than by the former process of demonstrating the necessary connection of concomitant effects, proceeding from an unknown cause.[1]

But, as regards the revolution of the apsides, one part of the force which determines it will probably have to be ascertained, by analogy, from its effects.

[1] The paper on the Secular Acceleration of the Moon's Motion which forms Chapter XIII. of *The New Principles of Natural Philosophy*, is an extension of the argument of these Propositions, and forms a practical corroboration of the above remarks.

Because the earth's perihelion has a motion of revolution similar to that of the moon's perigee; and therefore the arguments of this Proposition indicate the existence of a central force of rotation, bearing the same relation to the sun and earth as the sun does to the earth and moon.

The action of this force on the motion of the moon's perigee will be less than on that of the earth's perihelion, in proportion as the diameter of the moon's orbit about the earth is less than that of the earth about the sun. For its effect depends on the difference in the force of its action in opposite parts of the orbit.

PROPOSITION XXXVI.

Problem.—To apply Propositions XXXIV. and XXXV. to the disturbing action of the earth on the moon's orbital motion round the sun.

The earth's revolving force accelerates the orbital motion of the moon round the sun when the moon is outside the earth's orbit; the force of astral gravitation, drawing it from its orbit, then increases as the square of the increase of the velocity of the motion, and carries it farther and farther from the sun, until the decrease in the revolving force of the latter, and

the changing of the conjoint action of the disturbing force, reduce the velocity; and then the reduction of the astral force allows the moon to fall inwards towards the sun: and this falling towards the sun continues as the motion is retarded by the opposing action of the earth's force when the moon passes inside the earth's orbit, until the increase of the sun's revolving force and the changing of the earth's action from direct to less and less complete opposition cause a gradual acceleration of the motion, and a consequent increase of the astral force, which again draws it outwards from the sun.

Thus, in consequence of the action of an extraneous force alternately accelerating and retarding the moon's motion in its orbit round the sun, the alternate increase and decrease of the retarding force of astral gravitation carries the moon alternately inside and outside the normal line of its orbit.

PROPOSITION XXXVII.

Problem.—To apply Propositions XXXIV. and XXXV. to the motion of the satellites of Neptune round the sun.

In respect to the sun's rotation the satellites of Neptune revolve in the opposite direction round

Neptune to that in which the moon is revolved round the earth, from which it is to be inferred that Neptune rotates in that direction.

Therefore the acceleration caused by the disturbing force occurs when the satellite is inside the normal line of its orbit, and retardation when it is outside, so that, though the path described backwards and forwards across the normal line of the orbit will be similar to that described by the moon, the relative velocities of the motion at different distances from the sun will be reversed.

And, besides this, the action of the retardation of the moon's motion tending to bring it nearer to both of the centres of rotation, might be accomplished without any increase in the inclination of the planes of rotation.

But the acceleration of Neptune's satellite causing an increase of distance from both centres of rotation, could not be accomplished, whilst Neptune remained at the same distance from the sun, without throwing the satellite out of the plane in which Neptune and the sun rotate.

PROPOSITION XXXVIII.

Problem.—To determine the interaction of revolving forces.

1. Two equal forces revolving in the same direction, in the same plane, will mutually revolve each other; so that they will both revolve in an orbit whose diameter will be the radius of either of the orbits in which one endeavours to revolve the other.

2. If two equal forces revolve in planes at right angles to each other, the one whose axis lies in the plane of the rotation of the other will be revolved by the latter.

3. If two equal forces revolve in opposite directions in the same plane they cannot revolve each other, unless the equilibrium of their forces be disturbed by the action of some extraneous force.

4. Let each of the foregoing couples be revolved by the action of a greater central force of rotation.

And let this central force rotate in the same plane and in the same direction as the bodies in Section I.

Then, when these latter are equidistant from the central force, they are equally acted on by it, and therefore remain at their normal distance from each other.

But, as they advance in their orbital motions round each other, the one approaches and the other

recedes from the central force. And as the revolving force of the inner one accelerates the motion of the outer one round the central force, the centrifugal force of astral gravitation, increasing as the square of the velocity, carries the outer one farther from the common centre ; whilst at the same time the revolving force of the outer body retards the motion of the inner one round the common centre, and the consequent decrease of the centrifugal force of astral gravitation therefore lets it fall nearer to the common centre.

Thus, as the two bodies revolve round the central force, the revolution round each other is performed in an elliptical, instead of the circular orbit which their own undisturbed action would cause.

5. Then, as regards the action of this central force on the bodies in Section 2. In this case the body whose axis lies in the plane of rotation may for the present be regarded as having no axial rotation, as we consider the one which revolves it to revolve in the same plane as the central body.

In this case the action would be the same as in Section 4, except that, as there is no reciprocal revolving action between the two lesser bodies, the changing of the form of the orbit is not the same when the revolving body is inside as when it is outside the greater orbit ; and therefore the orbit of the non-rotating body round its primary, instead of being a true ellipse, is wider when the non-rotating body is

farther than its primary from the central force: because there is then a conjoint action of the revolving forces, as shown in Proposition XXXVI., Section 4, concerning the revolving action of the sun and earth upon the moon.

If the two motions of rotation were in opposite directions, then the conjoint action on the non-rotating body would occur when the latter was nearer than its primary to the central force, making the distortion of the ellipse the reverse of that resulting from the foregoing conditions.

6. As regards the action of the central force on the bodies in Section 3, supposing it to revolve in the same plane as they; then, if they be equidistant from the centre they would simply be swept round in the same orbit.

But, if the action of any extraneous force (such as a force causing an ellipticity of their orbit) prevent them from being equidistant, then, in their efforts at mutual revolution, the one nearer the common centre will be more retarded than the one more remote, and therefore the latter will have a motion onwards in its orbit round the former which will at the same time have a faster motion than it round the common centre.

Thus, whilst carried round the central force, they would be revolved about each other by the alternate preponderance of their revolving action.

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